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(54) **THERMALLY ADJUSTABLE SURGICAL SYSTEM AND METHOD**

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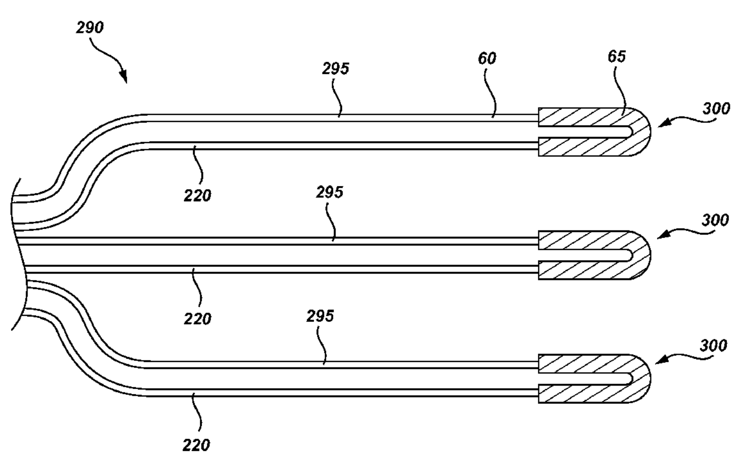
(57) **ABSTRACT**

A power source delivers oscillating electrical energy to an electrical conductor, such as a wire or catheter, which is coated circumferentially with a ferromagnetic material in a selected region. With high frequency electrical energy, the ferromagnetic material has a quick response in heating and cooling adjustable by the controllable power delivery. The ferromagnetic material can be used for separating tissue, coagulation, tissue destruction or achieving other desired tissue effects in numerous surgical procedures.

27 Claims, 27 Drawing Sheets



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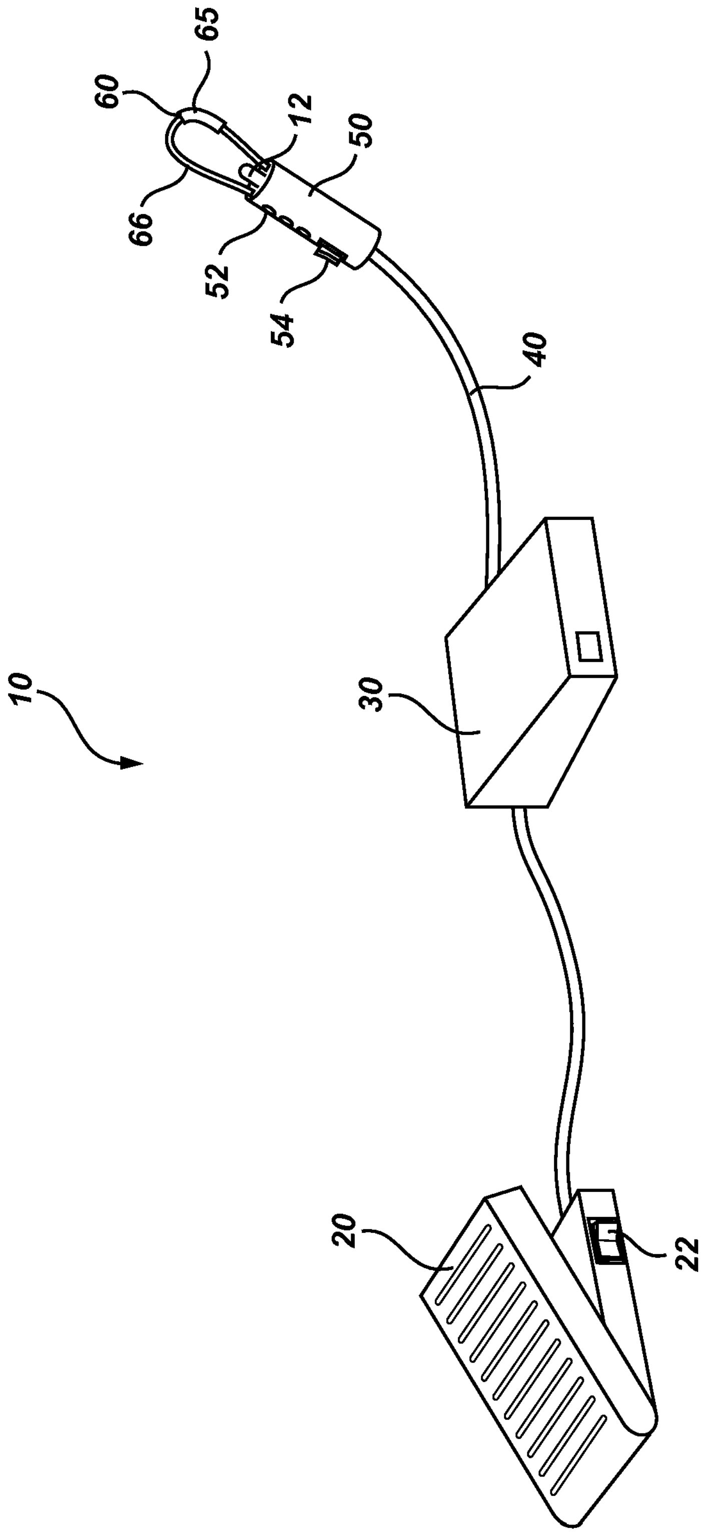


Fig. 1

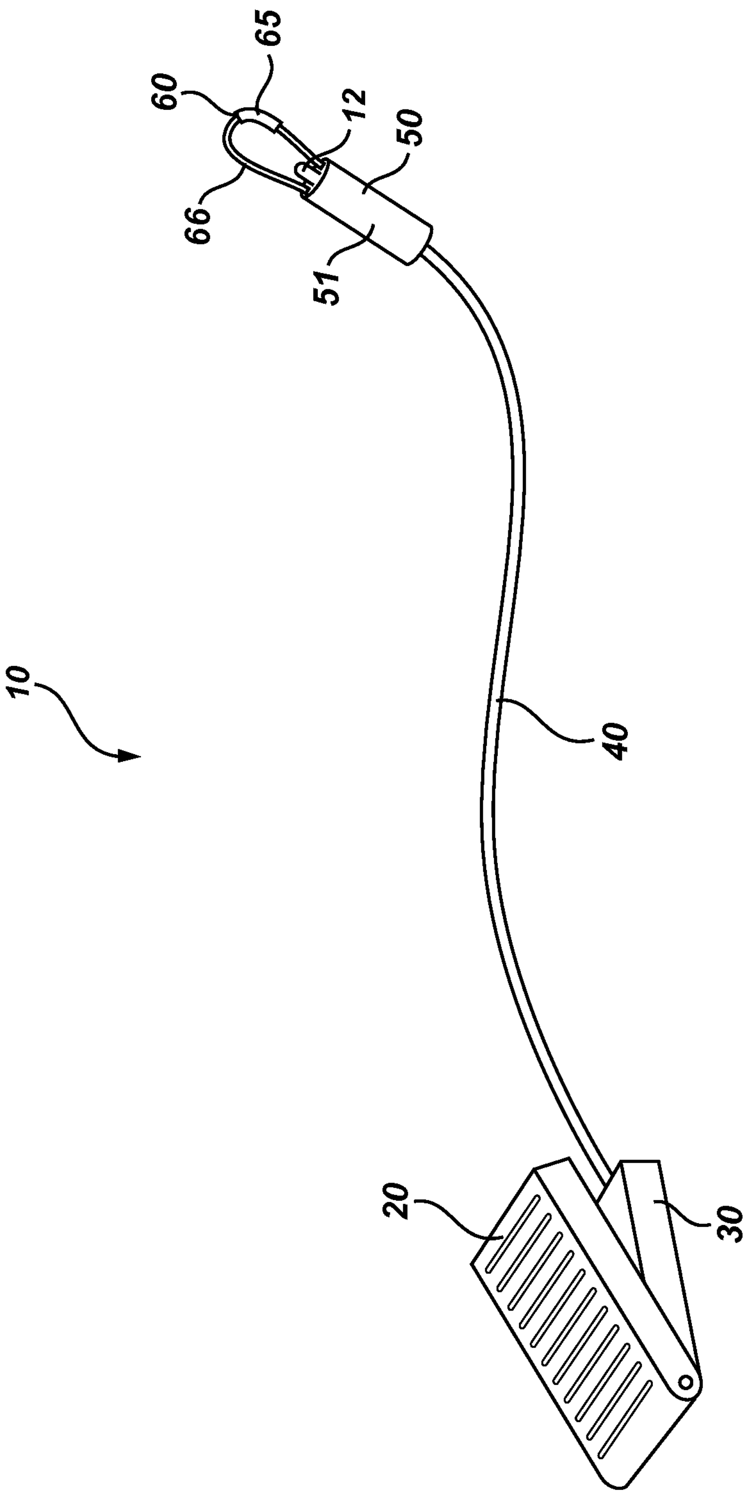
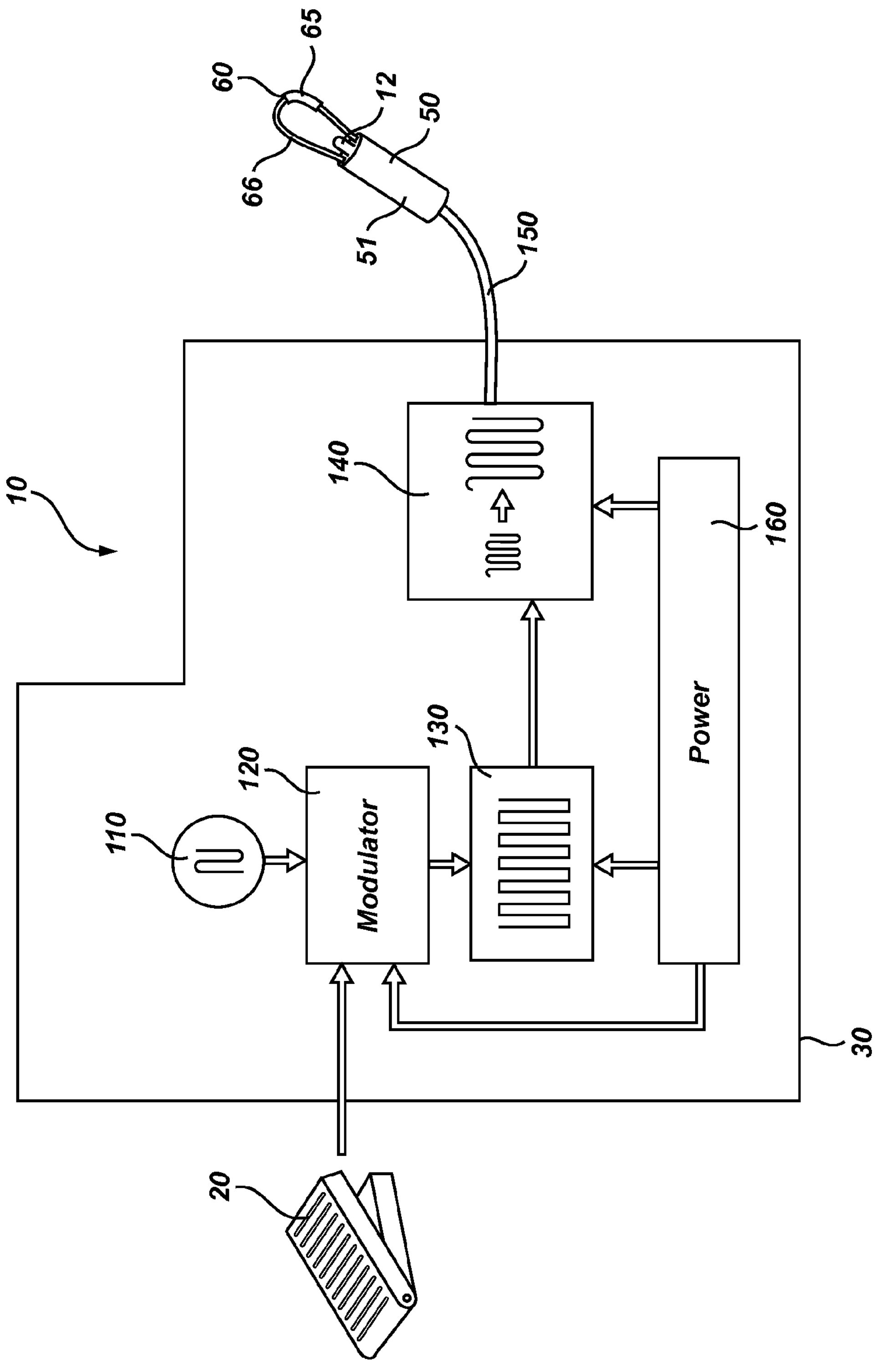


Fig. 2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110
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Modulator
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Power
30
20

Fig. 3

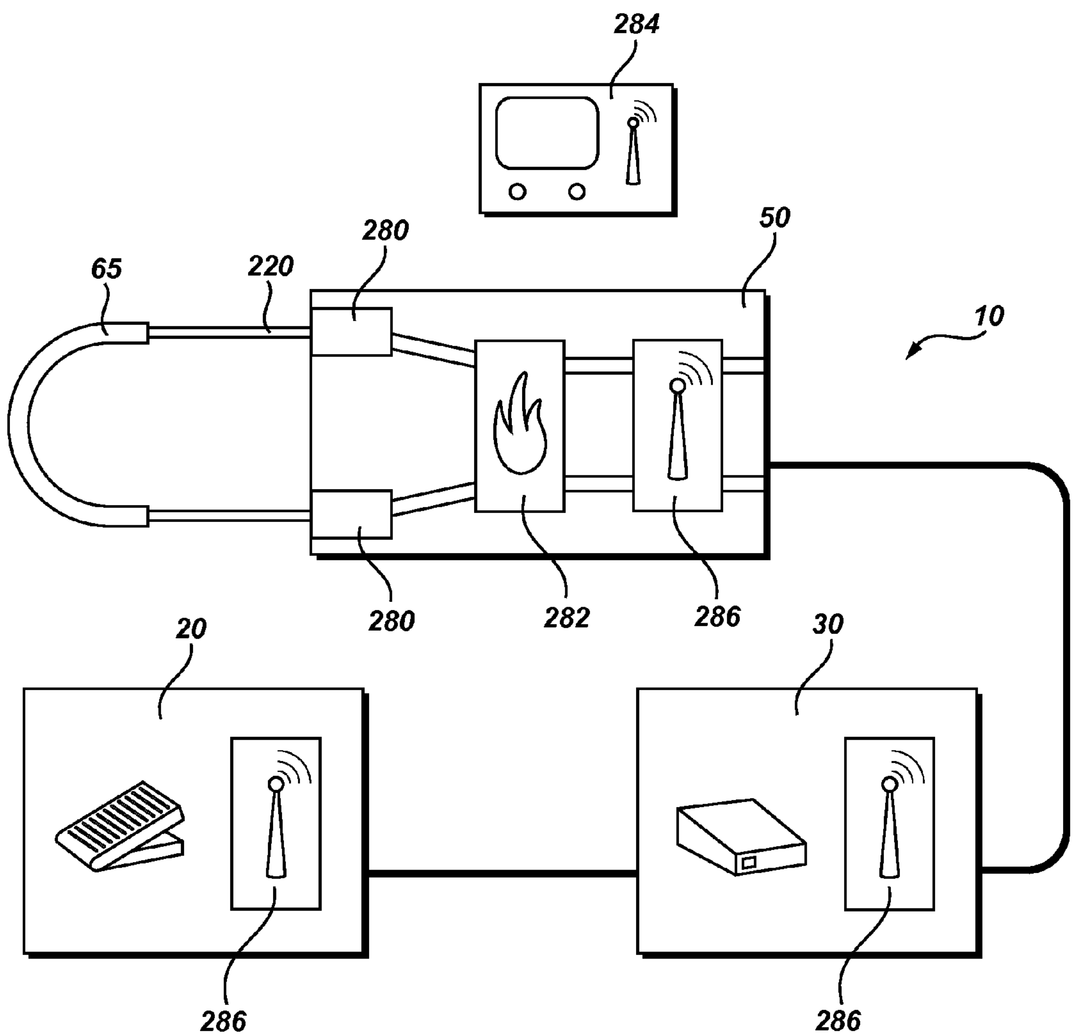


Fig. 4A

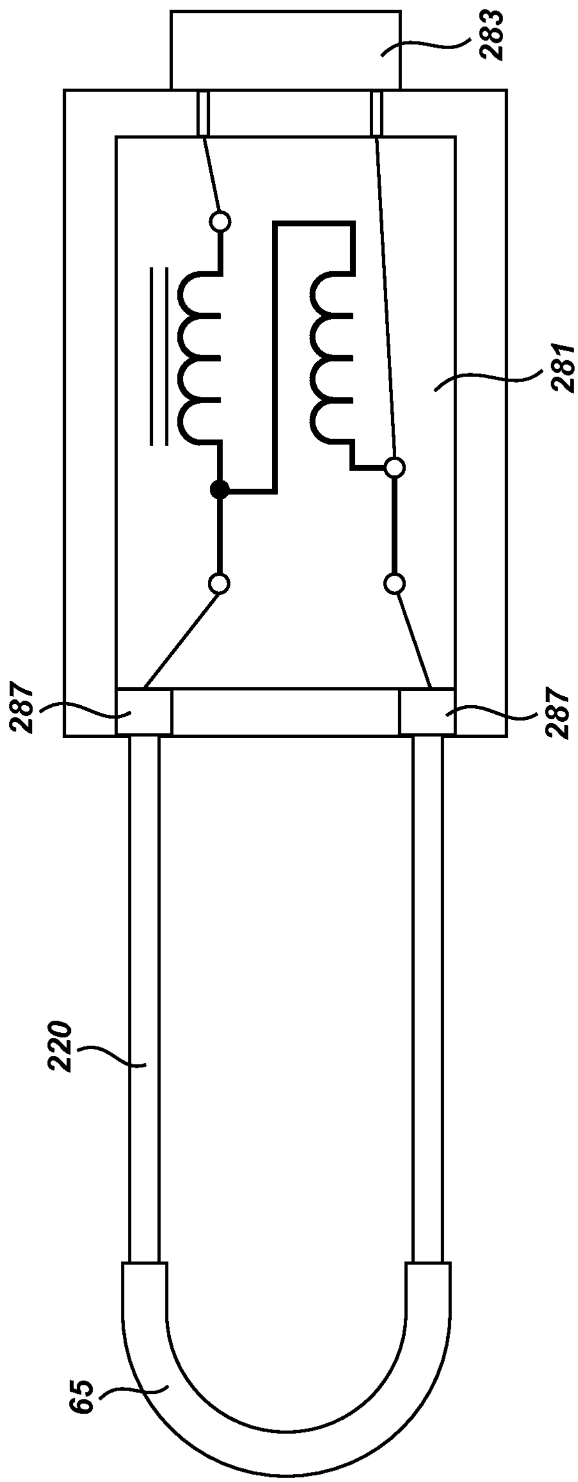


Fig. 4B

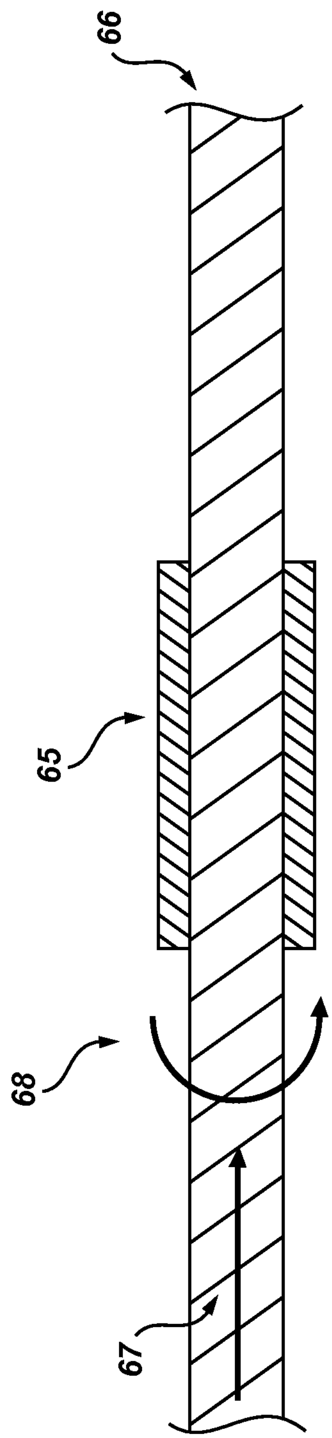


Fig. 5A

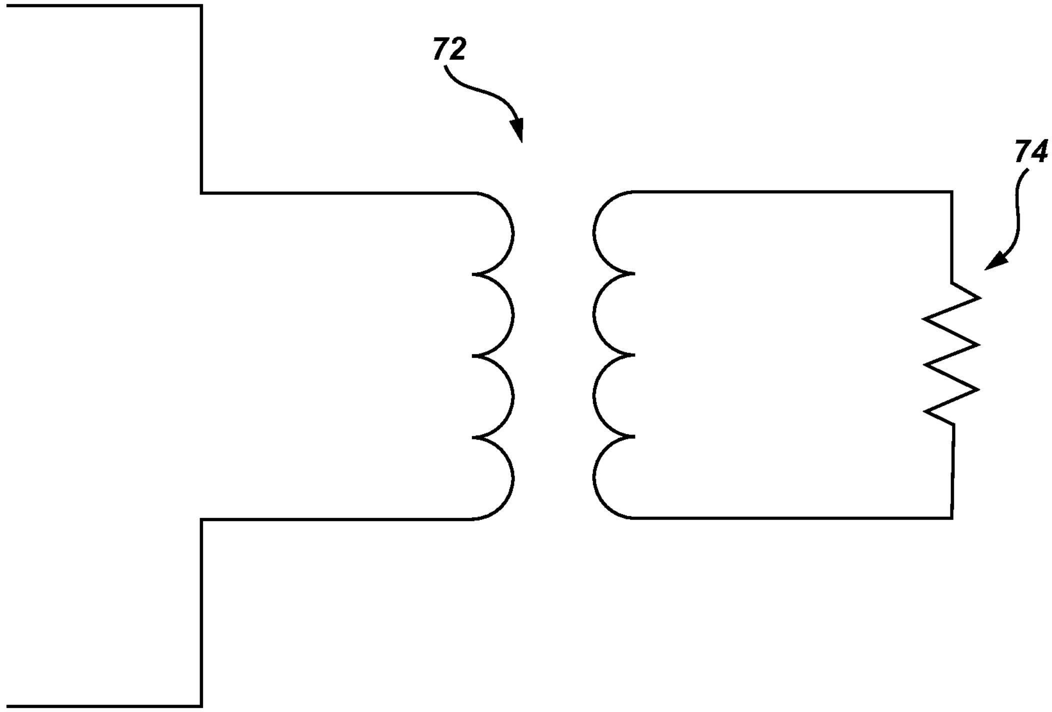


Fig. 5B

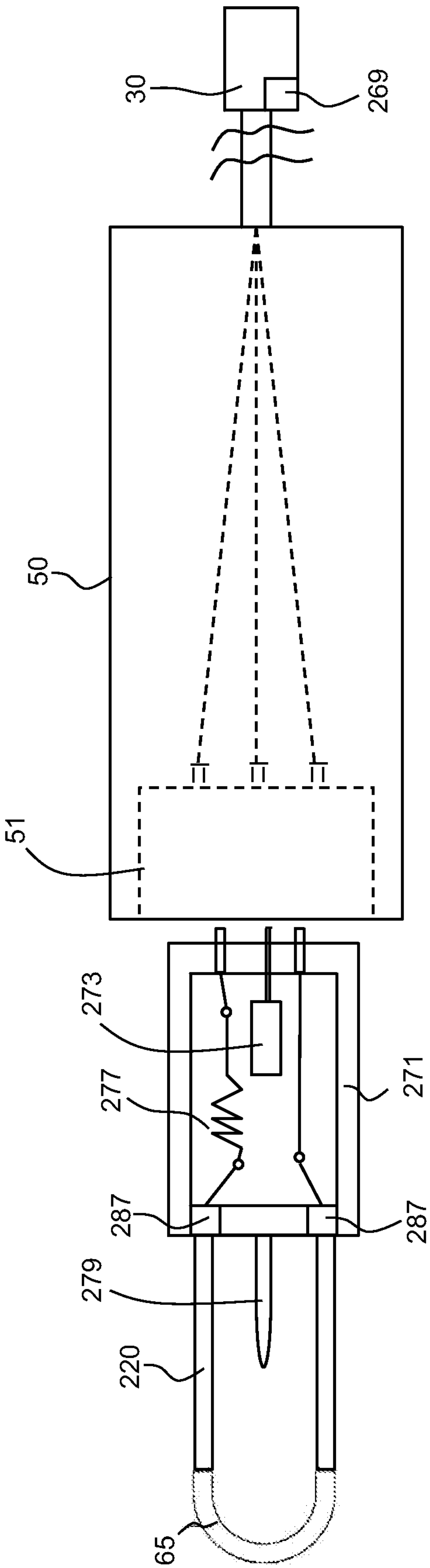


Fig. 5C

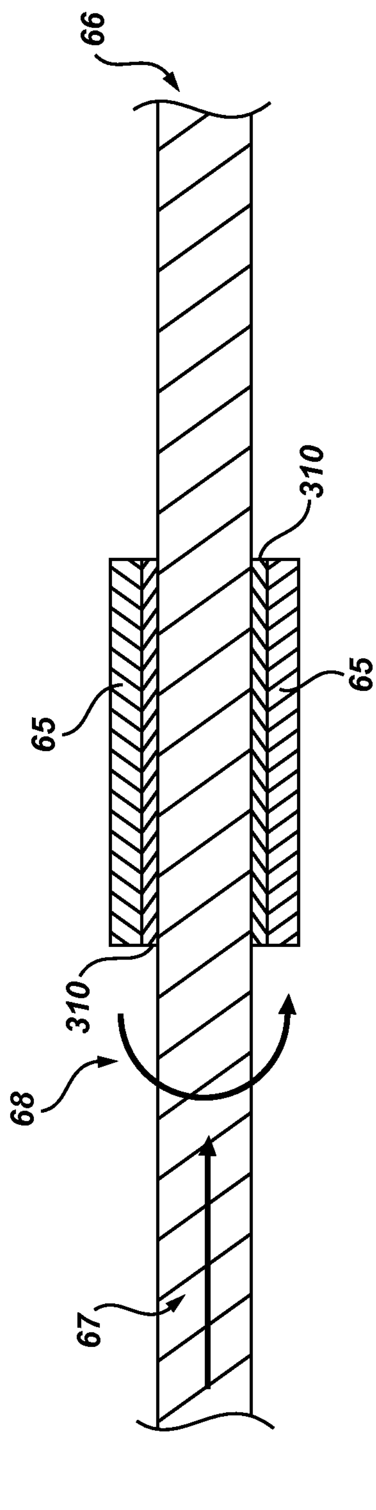


Fig. 6

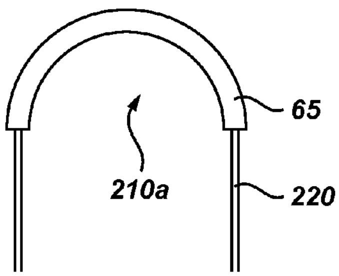


Fig. 7A

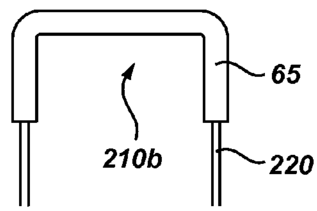


Fig. 7B

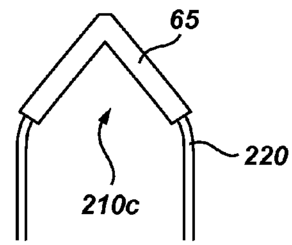


Fig. 7C

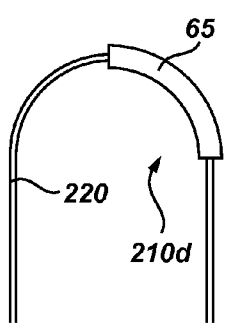
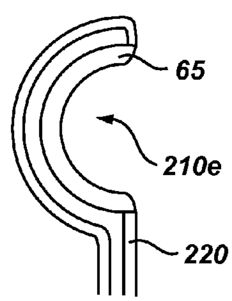


Fig. 7D



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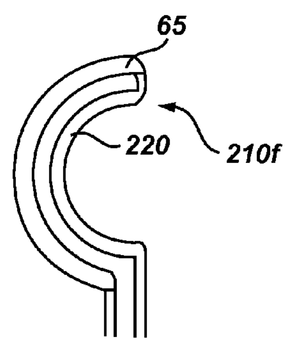


Fig. 7F

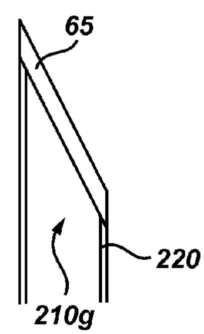


Fig. 7G

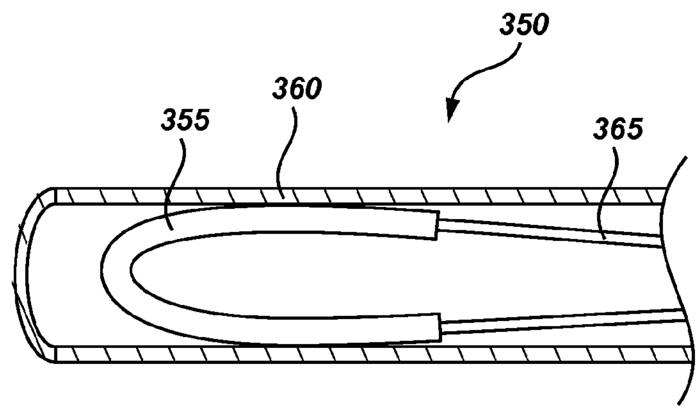
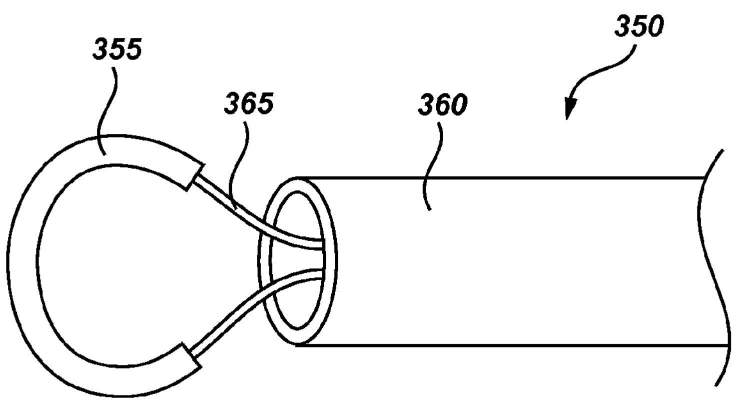


Fig. 8



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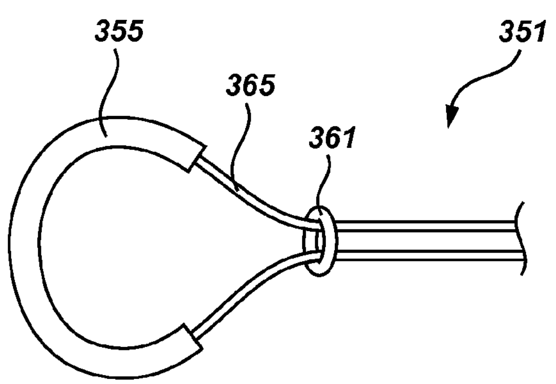


Fig. 9B

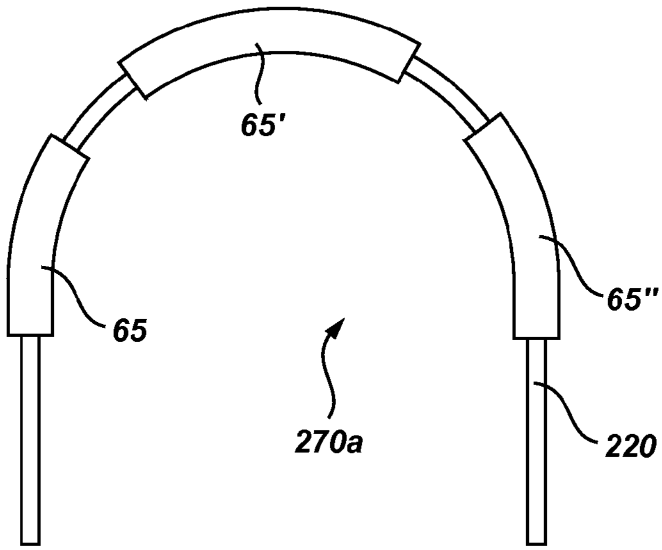


Fig. 10A

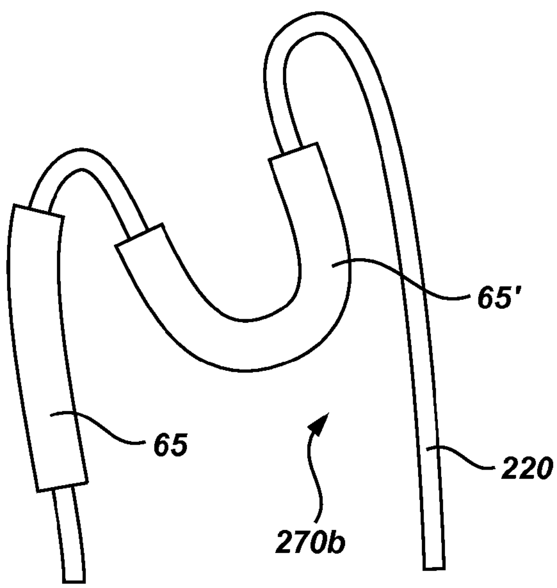


Fig. 10B

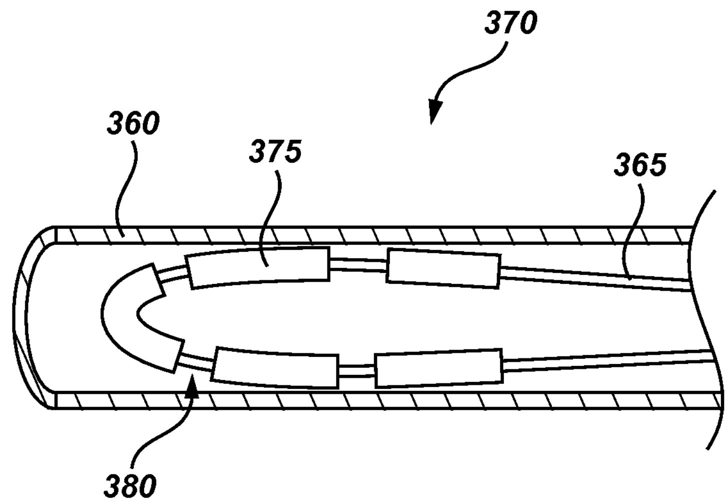


Fig. 11

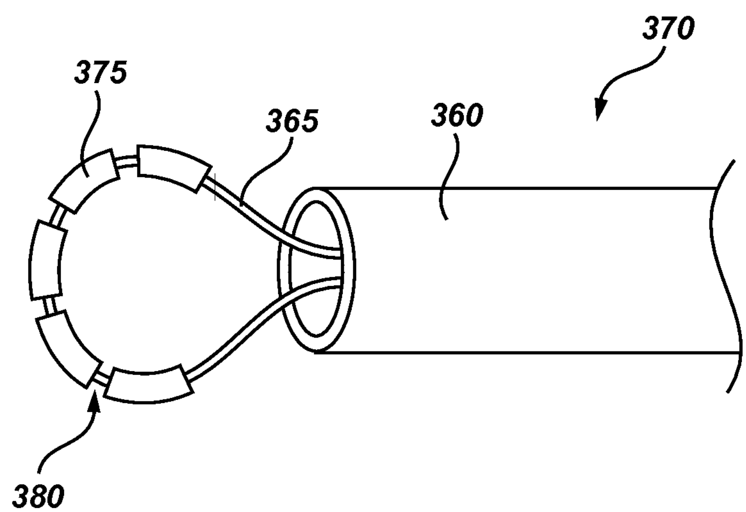
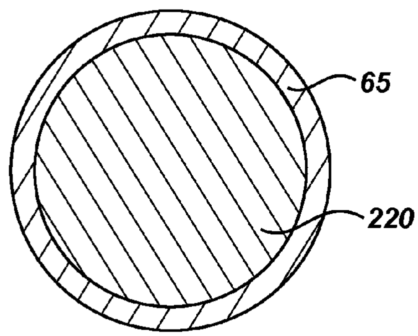


Fig. 12



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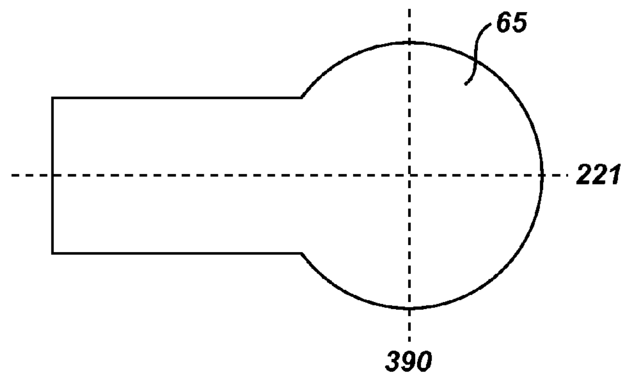


Fig. 14A

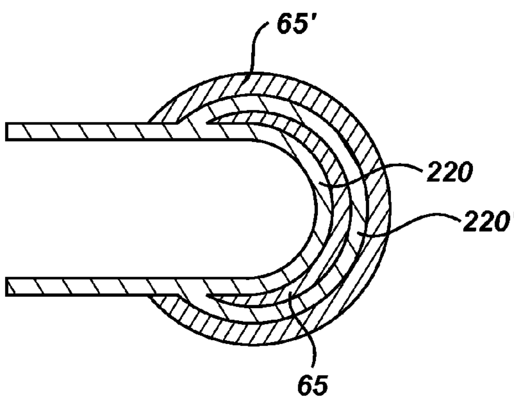


Fig. 14B

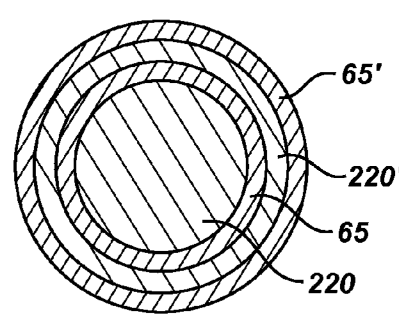


Fig. 15

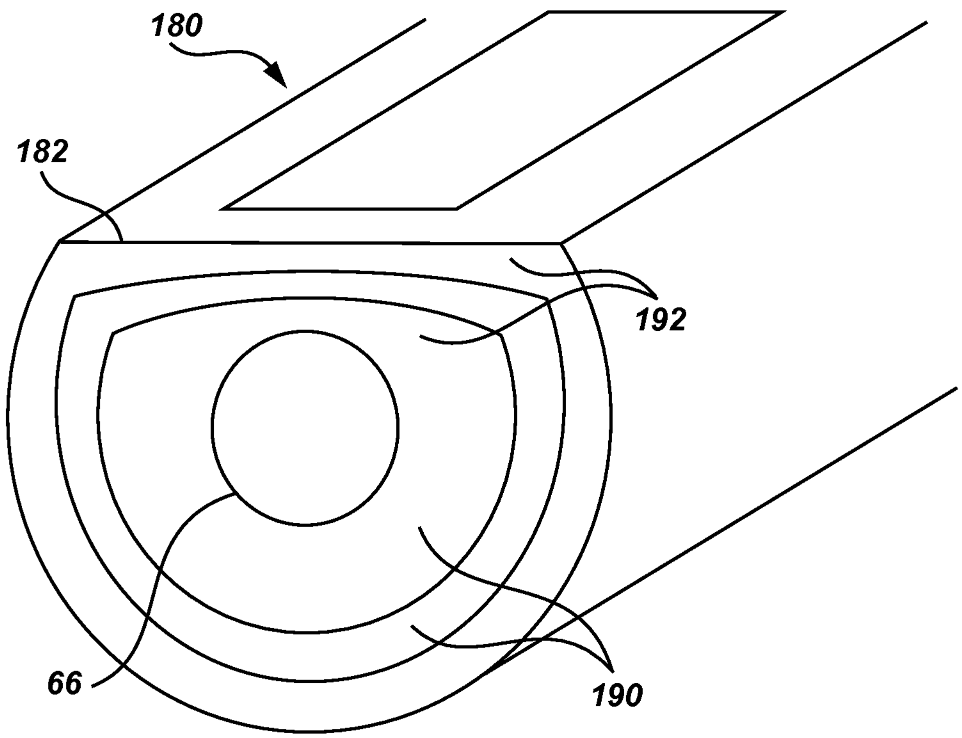


Fig. 16

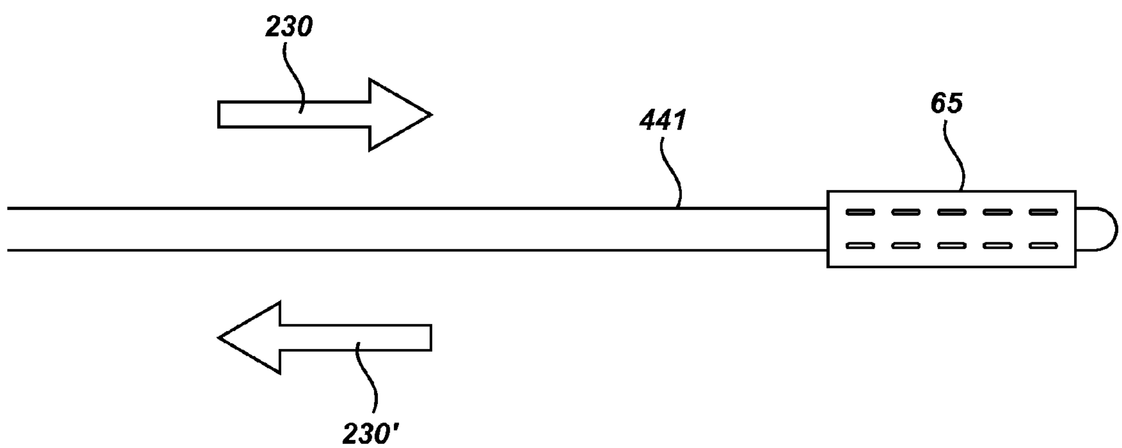
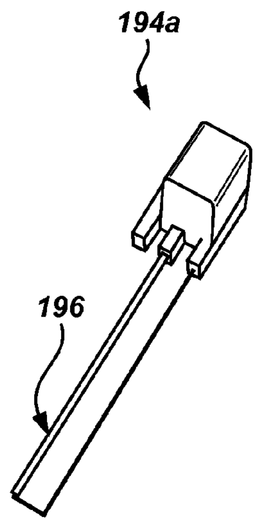


Fig. 17



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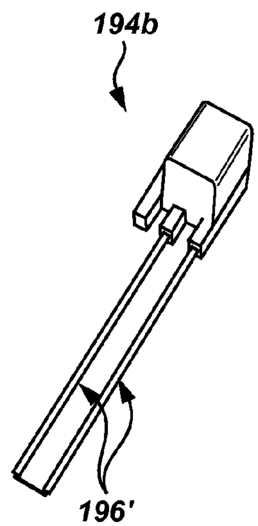

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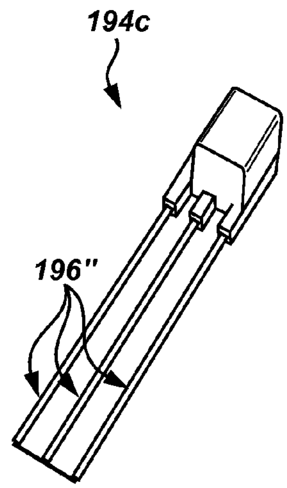

Fig. 18C

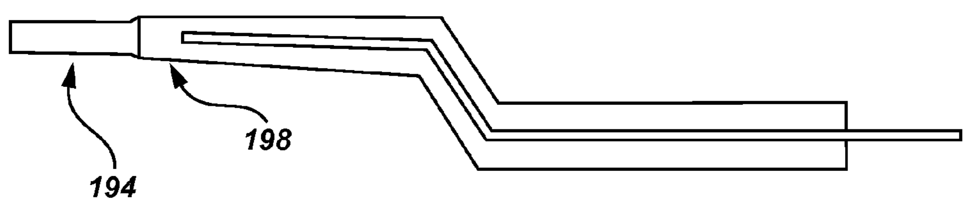

Fig. 18D

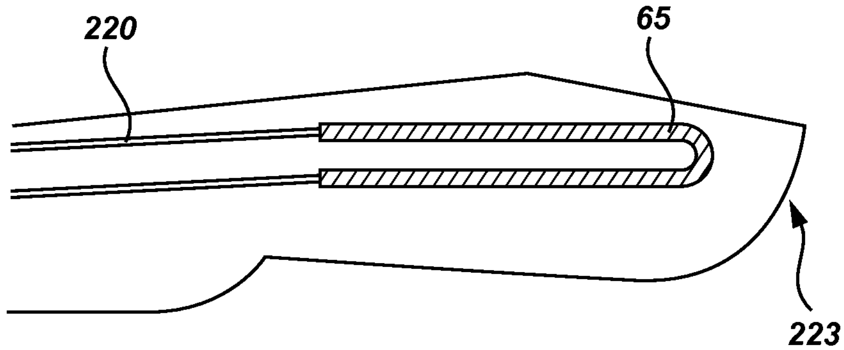

Fig. 19A

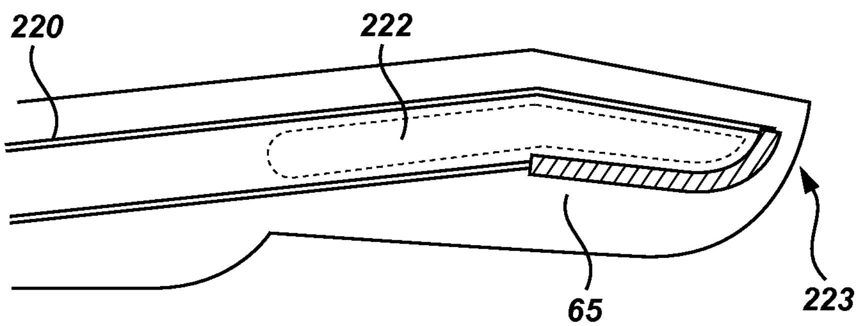

Fig. 19B

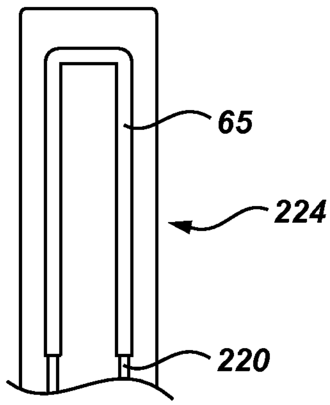

Fig. 20A

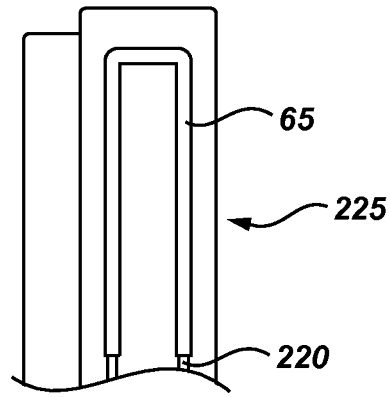

Fig. 20B

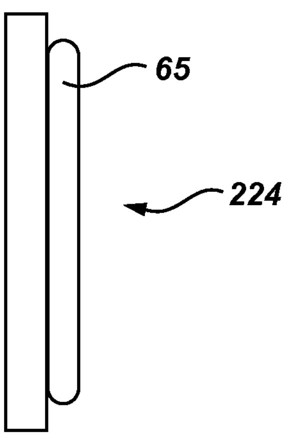

Fig. 20C

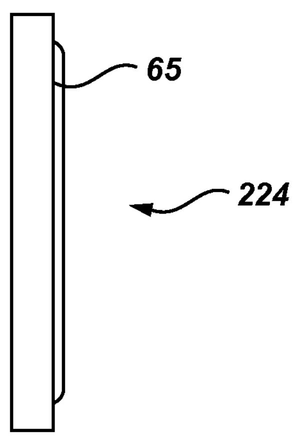

Fig. 20D

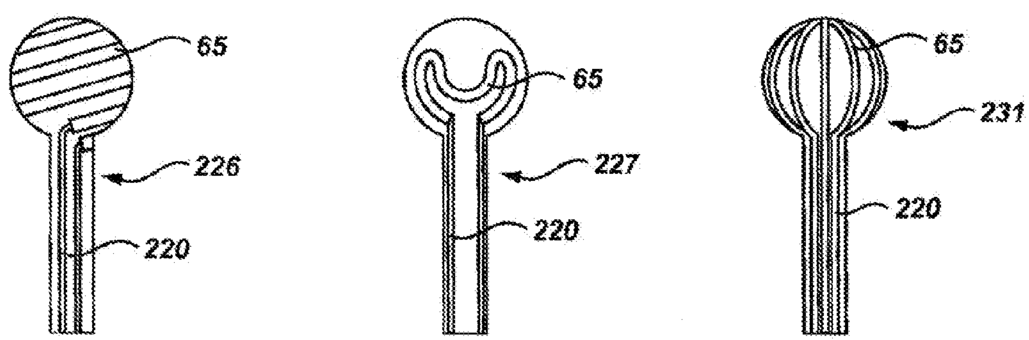

Fig. 21A Fig. 21B Fig. 21C

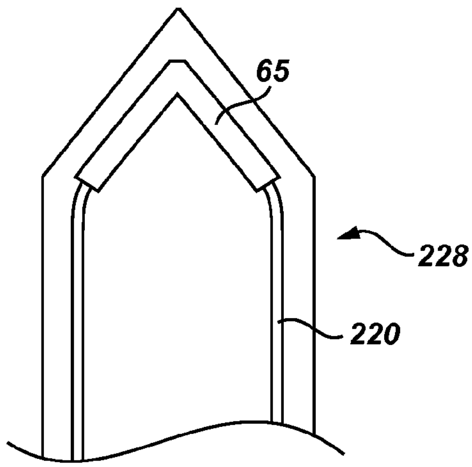

Fig. 22A

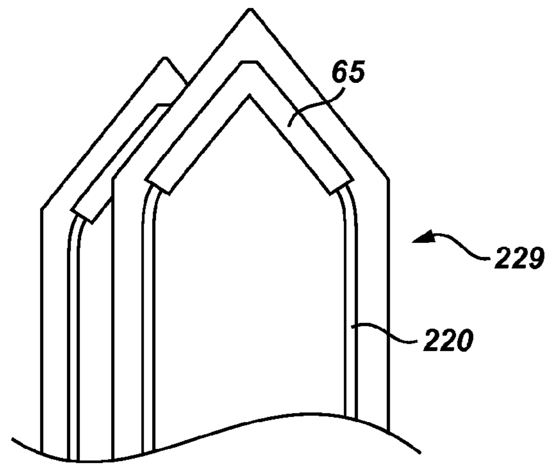

Fig. 22B

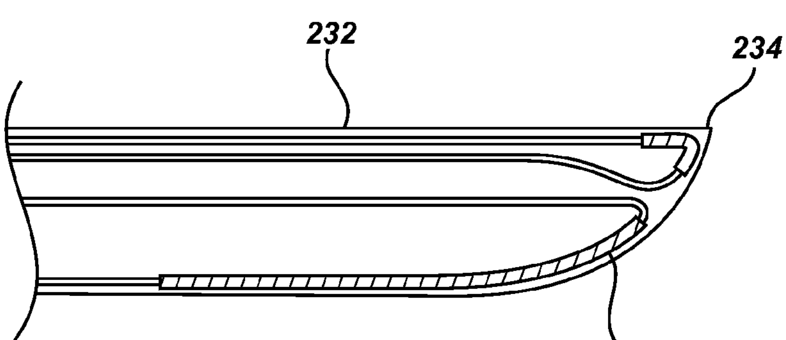

Fig. 22C

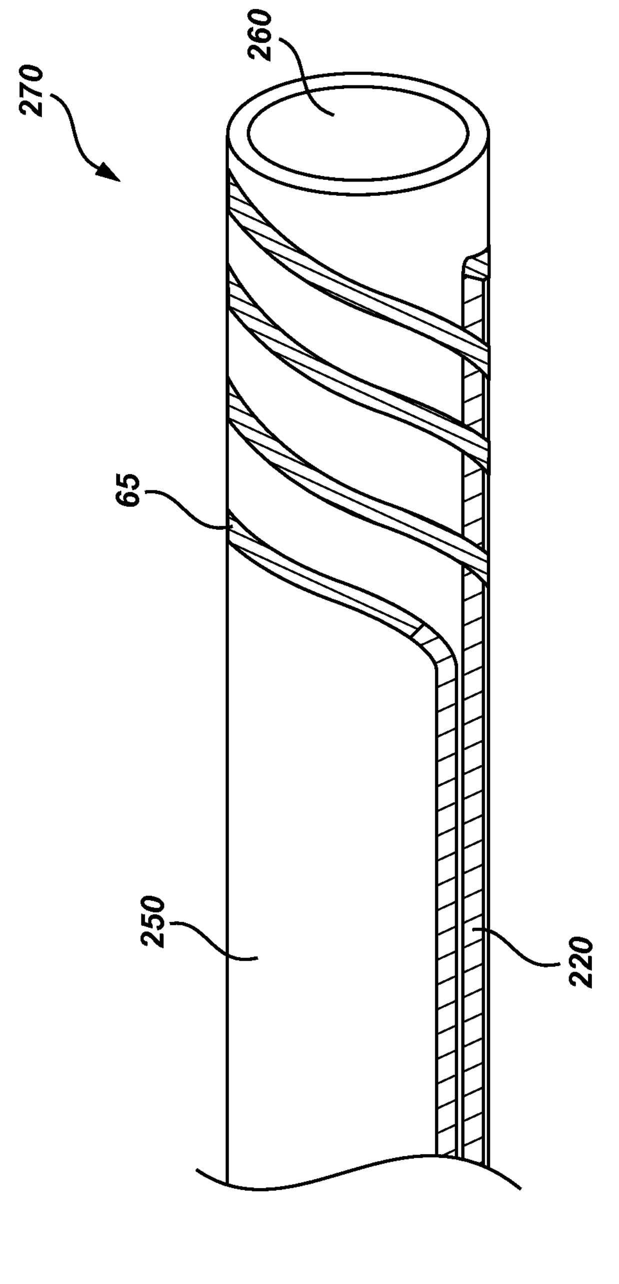

Fig. 23A

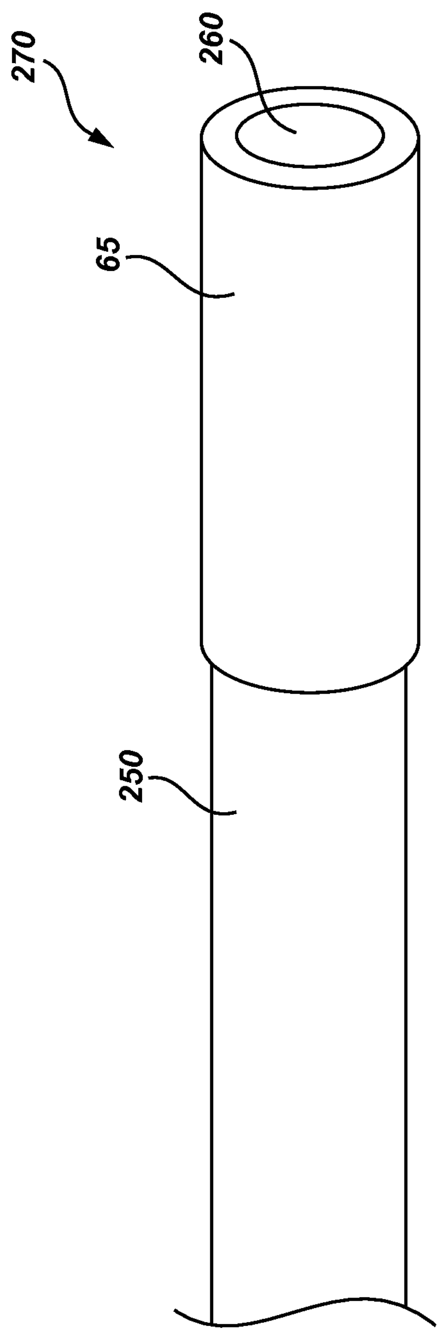

Fig. 23B

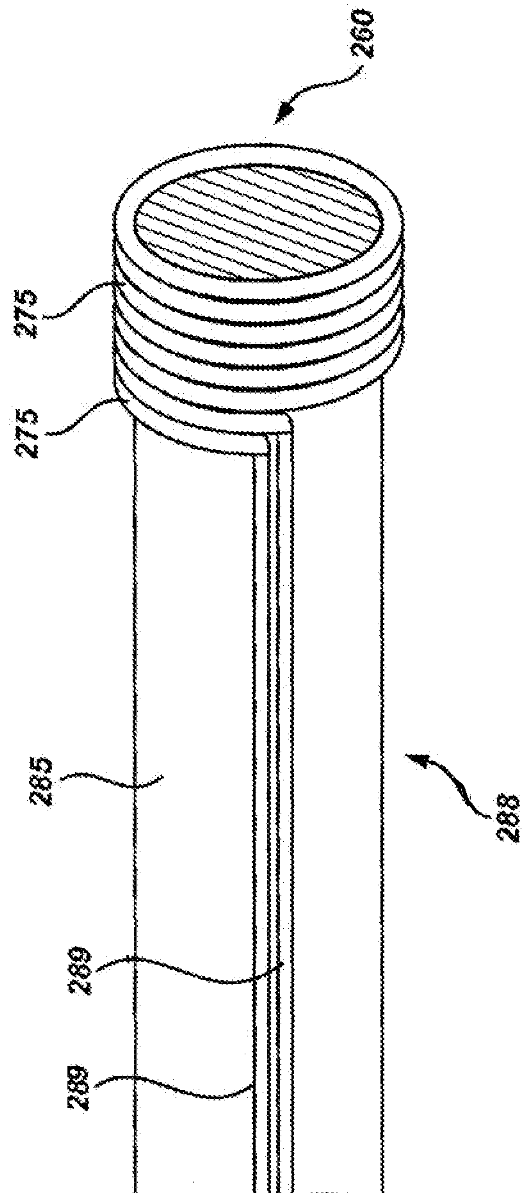

Fig. 24

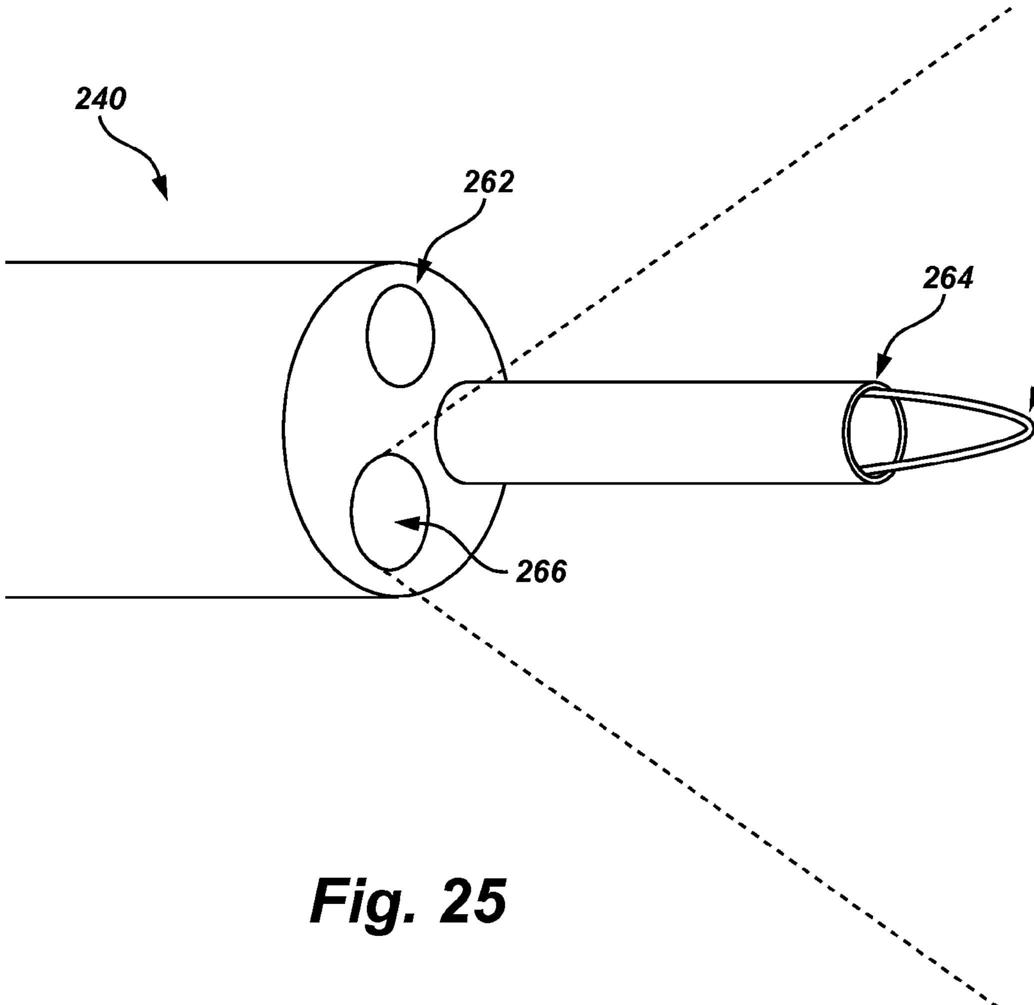

Fig. 25

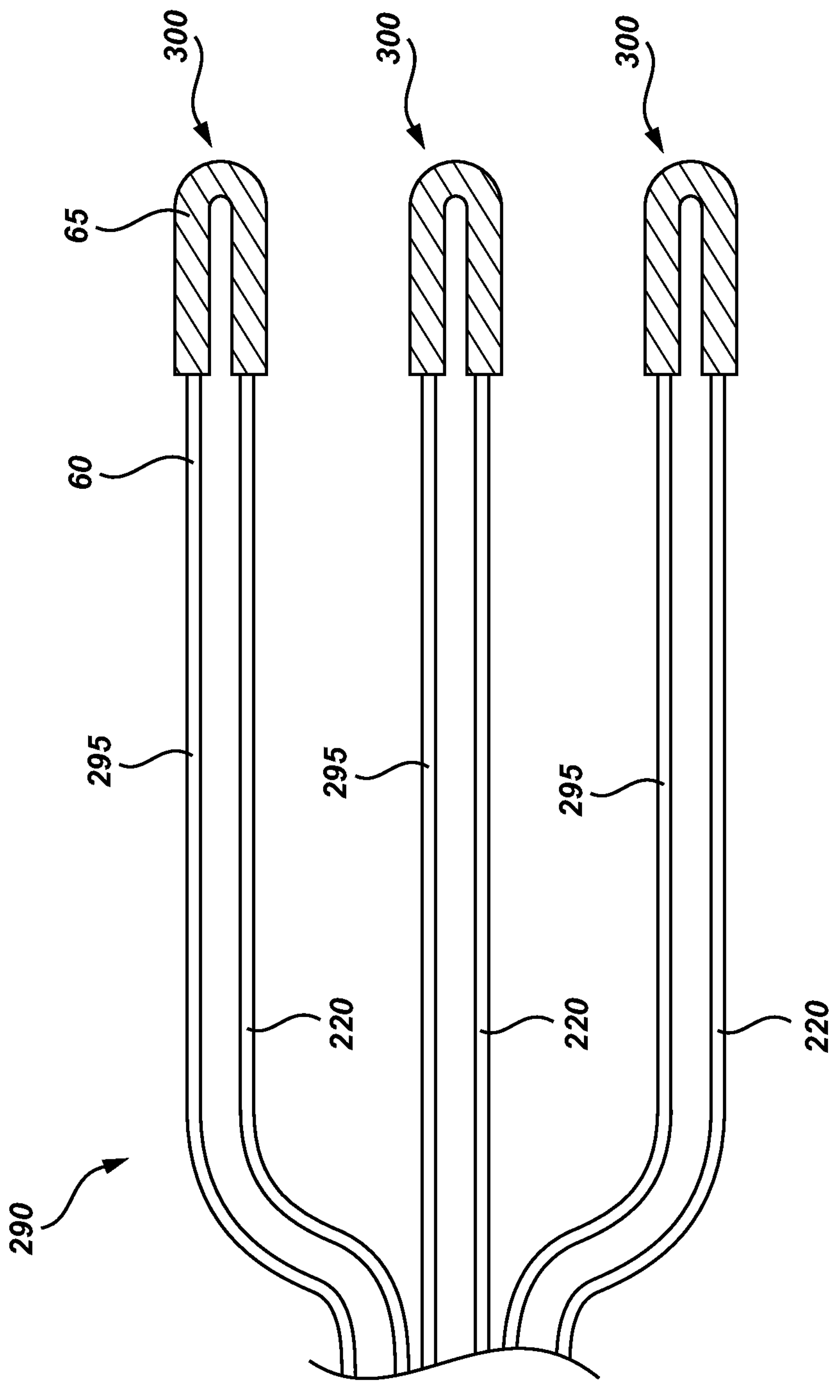

Fig. 26

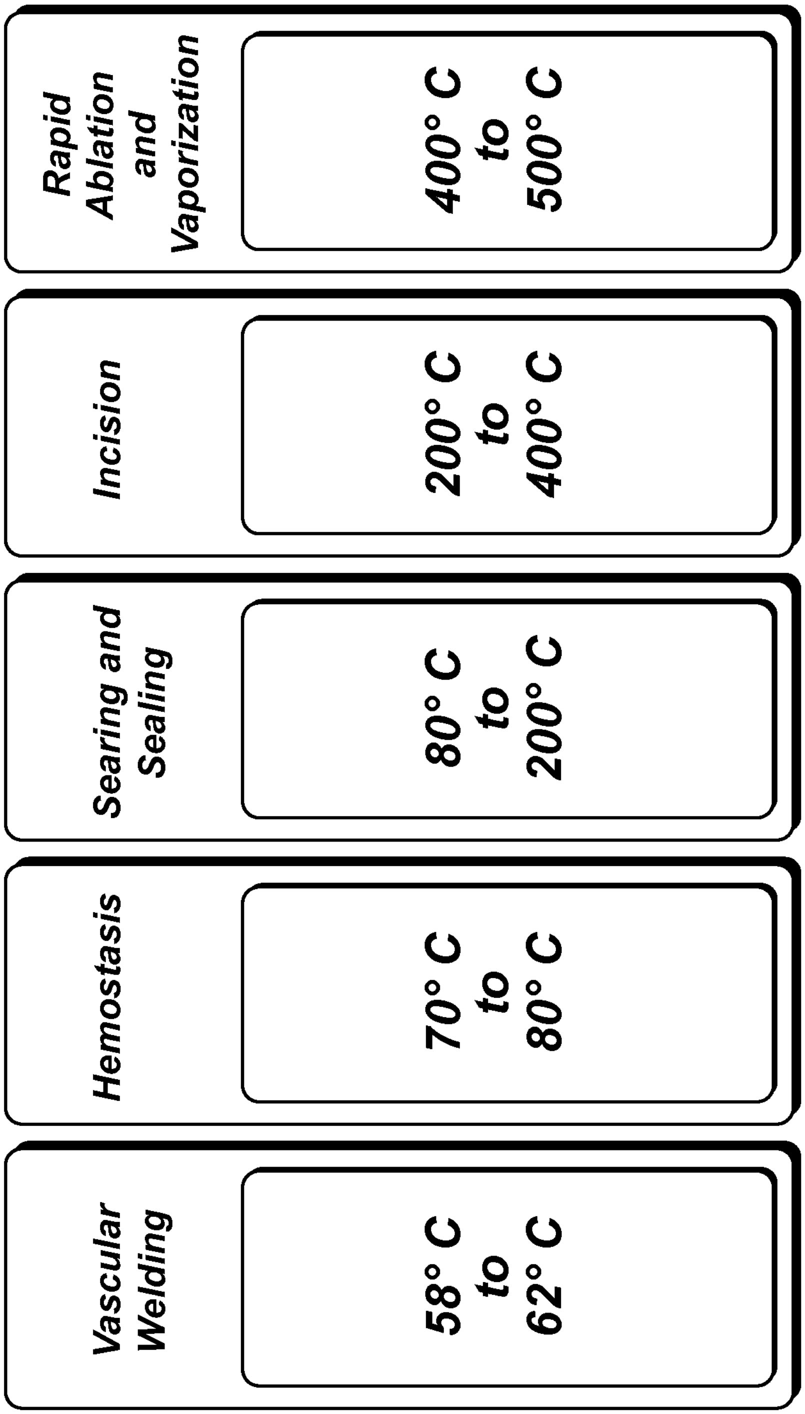
Vascular Welding
58° C to 62° C
Hemostasis
70° C to 80° C
Searing and Sealing
80° C to 200° C
Incision
200° C to 400° C
Rapid Ablation and Vaporization
400° C to 500° C

Fig. 27

THERMALLY ADJUSTABLE SURGICAL SYSTEM AND METHOD

RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/170,203, filed Apr. 17, 2009, U.S. Provisional Patent Application Ser. No. 61/170,220, filed Apr. 17, 2009, and U.S. Provisional Patent Application Ser. No. 61/170,207, filed Apr. 17, 2009 which are incorporated hereby by references in their entirety.

This application is a part of U.S. patent application Ser. No. 12/647,340 filed Dec. 24, 2009, now U.S. Pat. No. 8,419,724 issued Apr. 16, 2013, now Issued U.S. Pat. No. 8,377,052 issued Feb. 19, 2013; U.S. patent application Ser. No. 12/647,344 filed Dec. 24, 2009, U.S. patent application Ser. No. 12/647,350 filed Dec. 24, 2009, now U.S. Pat. No. 8,430,870 issued Apr. 30, 2013; U.S. patent application Ser. No. 12/647,355 filed Dec. 24, 2009, now U.S. Pat. No. 8,506,561 issued Aug. 13, 2013; U.S. patent application Ser. No. 12/647,358 filed Dec. 24, 2009; now U.S. Pat. No. 8,292,879, issued Oct. 23, 2012; U.S. patent application Ser. No. 12/647,363 filed Dec. 24, 2009; now U.S. Pat. No. 8,523,850 issued Sep. 3, 2013; U.S. patent application Ser. No. 12/647,302 filed Dec. 24, 2009; now U.S. Pat. No. 8,372,066 issued Feb. 12, 2013; U.S. patent application Ser. No. 12/647,329 filed Dec. 24, 2009; now U.S. Pat. No. 8,491,578 issued Jul. 23, 2013; U.S. patent application Ser. No. 12/647,374 filed Dec. 24, 2009; now U.S. Pat. No. 8,523,851 issued Sep. 3, 2013; U.S. patent application Ser. No. 12/647,376 filed Dec. 24, 2009; and now U.S. Pat. No. 8,414,569 issued Apr. 9, 2013; U.S. patent application Ser. No. 12/647,380 filed Dec. 24, 2009, each of which is incorporated hereby by reference in its entirety.

BACKGROUND OF THE INVENTION

1. The Field of the Invention

The present invention relates to surgical tools. More specifically, the present invention relates to thermally adjustable tools used in open and minimally invasive surgical procedures and interventional surgical and therapeutic procedures.

2. State of the Art

Surgery generally involves cutting, repairing and/or removing tissue or other materials. These applications are generally performed by cutting tissue, fusing tissue, or tissue destruction.

Current electrosurgery modalities used for cutting, coagulating, desiccating, ablating, or fulgurating tissue, have undesirable side effects and drawbacks.

Monopolar and bipolar electrosurgery modalities generally have disadvantages relating to "beyond the tip" effects. These effects are caused by passing alternating current through tissues in contact with conducting instruments or probes.

Monopolar surgical instruments require electric current to pass through the patient. A return electrode is placed on the patient, often on the patient's thigh. Electricity is conducted from a "knife" electrode through the tissue and returns through the return electrode. Other forms of monopolar instruments exist, such as those which use the capacitive effect of the body to act as the return electrode or ground.

A low voltage high frequency waveform will incise, but has little hemostatic effect. A high voltage waveform will cause adjacent tissue hemostasis and coagulation. Therefore, when hemostasis is desirable, high voltage is used. The high voltage spark frequently has deeper tissue effects than the cut because the electricity must pass through the patient. The damage to

the tissue extends away from the actual point of coagulation. Furthermore, there are complaints of return electrode burns. Yet, any reduction of voltage reduces the effectiveness of hemostasis. Further, the temperature of the spark or arc cannot be precisely controlled, which can lead to undesirable charring of target tissue.

Bipolar surgical instruments can produce tissue damage and problems that are similar to monopolar devices, such as sparking, charring, deeper tissue effects and electric current damage away from the application of energy with varying effects due to the differing electrical conductivity of tissue types, such as nerve, muscle, fat and bone, and into adjacent tissues of the patient. However, the current is more, but not completely, contained between the bipolar electrodes. These electrodes are also generally more expensive because there are at least two precision electrodes that must be fabricated instead of the one monopolar electrode.

Electrocautery resistive heating elements reduce the drawbacks associated with charring and deeper tissue damage caused by other electrosurgery methods. However, such devices often present other tradeoffs, such as the latency in controlling heating and cooling time, and effective power delivery. Many resistive heating elements have slow heating and cooling times, which makes it difficult for the surgeon to work through or around tissue without causing incidental damage.

Tissue destruction instruments generally heat tissue to a predetermined temperature for a period of time to kill, or ablate, the tissue. In some controlled heating of tissues, a laser is directed to an absorptive cap to reach and maintain a predetermined temperature for a predetermined amount of time. While this provides the benefits of thermal heating, it is expensive due to the complexity and expense of laser hardware.

In another tissue destruction procedure, a microwave antenna array is inserted into the tissue. These arrays are powered by instruments that cause microwave energy to enter and heat the tissue. While such devices are often effective at killing, or ablating, the desired tissue, they often cause deeper tissue effects than the desired area. Additionally the procedures can require expensive equipment.

Tissue destruction with resistively heated tools can produce unintended collateral tissue damage, in addition to having slow heating and cooling attributes.

Use of ferrite beads and alloy mixes in ceramics have been examined as alternatives. When excited by the magnetic field associated with high frequency current passing through a conductor, ferrite beads and alloy mixes in ceramics can reach high temperatures very quickly. However, one major problem with the use of these materials is that a large temperature differential can cause the material to fracture, especially when it comes into and out of contact with liquids. In other words, if a hot ferrite surgical instrument is quenched by a cooler pool of liquid, such as blood or other body fluids, the material's corresponding temperature drops rapidly and may cause the material to fracture. These fractures not only cause the tool to lose its effectiveness as a heat source, because the magnetic field is disrupted, but may require extraction of the material from the patient. Obviously, the need to extract small pieces of ferrite product from a patient is highly undesirable. Thus, there is a need for an improved thermal surgical tool.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved thermally adjustable surgical or therapeutic tool and a method of using the same.

According to one aspect of the invention, a thermal surgical tool system is provided with a ferromagnetic coating over a conductor and an oscillating electrical energy source for generating heat at the location of the coating. The oscillating electrical energy may cause inductive heating of the ferromagnetic coating to thereby enable the cutting, ablating, etc., of tissue.

In accordance with another aspect of the invention, the thermal surgical tool system is provided with a power control mechanism which enables the surgeon to quickly adjust the power to the surgical or therapeutic tool to achieve desired tissue welding, cutting, ablation, vaporization, etc., depending on the amount of power supplied to the tool. This may provide the advantage of allowing the surgeon to only deliver a thermal effect at desired locations, which may also prevent the accidental delivery of undesired thermal effects while waiting for the tool to cool.

According to another aspect of the invention, a thermal surgical tool system may be configured so that the power delivery to a ferromagnetic element may be altered by the surgeon in near real-time to achieve different tissue effects, including hemostasis, tissue welding and tissue destruction.

According to another aspect of the invention, controlled thermal tissue destruction may be performed.

According to another aspect of the invention, the coated conductor may be powered by a generator and incorporated in a catheter or endoscope, which could also provide for sensing, viewing, aspiration, irrigation, delivery of a thermally-cured material, or removal of a thermally-melted or ablated material, through a channel.

According to another aspect of the invention a catheter may be used to deliver a ferromagnetic coated conductor into an area for a desired therapeutic effect.

According to another aspect of the invention, the heating of the ferromagnetic coating may be directed by changing characteristics of the power delivered to the conductor.

According to another aspect of the invention, a plurality of ferromagnetic conductors may be disposed on a primary geometry, each conductor being individually controlled such that the ferromagnetic conductors may provide different tissue effects at the same time.

These and other aspects of the present invention are realized in a thermally adjustable surgical tool as shown and described in the following figures and related description.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present invention are shown and described in reference to the numbered drawings wherein:

FIG. **1** shows a perspective view of a thermal surgical tool system in accordance with the principles of the present invention;

FIG. **2** shows a perspective view of an alternate embodiment of a thermal surgical tool system in accordance with the present invention;

FIG. **3** shows a diagram of a thermal surgical tool system in accordance with the principles of the present invention;

FIG. **4**A shows a thermal surgical tool system with heat prevention terminals, heat sink, and wireless communication devices;

FIG. **4**B shows a thermal surgical tool system with impedance matching network;

FIG. **5**A shows a close-up, side cross-sectional view of a single layer ferromagnetic coated conductor tip in accordance with one aspect of the present invention;

FIG. **5**B shows an electrical equivalent representation of FIG. **5**A's ferromagnetic coated conductor;

FIG. **5**C shows a side view of one configuration of a thermal surgical tool handle and ferromagnetic coated conductor in accordance with one aspect of the present disclosure;

FIG. **6** shows a close-up, side cross-sectional view of a single layer ferromagnetic coated conductor tip with a thermal insulator in accordance with one aspect of the present invention;

FIG. **7**A shows a close-up view of ferromagnetic coated conductor surgical tool tip with a loop geometry and FIG. **7**B shows a close-up view of a ferromagnetic coated conductor surgical tool tip with a generally square geometry in accordance with aspects of the present invention;

FIG. **7**C shows a close-up view of a ferromagnetic coated conductor surgical tool tip with a pointed geometry;

FIG. **7**D shows a close-up view of a ferromagnetic coated conductor surgical tool tip with an asymmetrical loop geometry;

FIG. **7**E shows a close-up view of a ferromagnetic coated conductor surgical tool tip with a hook geometry in which the concave portion may be used for therapeutic effect, including cutting;

FIG. **7**F shows a close up view of a ferromagnetic coated conductor surgical tool tip with a hook geometry in which the convex portion may be used for therapeutic effect, including cutting;

FIG. **7**G shows a close up view of a ferromagnetic coated conductor surgical tool tip with an angled geometry;

FIG. **8** shows a cut-away view of a retracted snare;

FIG. **9**A shows a side view of an extended snare;

FIG. **9**B shows an alternate embodiment of an extended snare;

FIG. **10**A shows a close-up view of a ferromagnetic coated conductor surgical tool with a loop geometry and linear array of coatings;

FIG. **10**B shows a close up view of a ferromagnetic coated conductor surgical tool with an alternate hook geometry and linear array;

FIG. **11** shows a cut-away view of a retracted snare with an array of coatings;

FIG. **12** shows a side view of an extended snare with a linear array of coatings;

FIG. **13** shows an axial cross-sectional view of a single layer ferromagnetic coated conductor surgical tool in the ferromagnetic-coated region;

FIG. **14**A shows a perspective view of a multi-layer ferromagnetic coated conductor surgical tool tip;

FIG. **14**B shows a side cross-sectional view of a multi-layer ferromagnetic coated conductor surgical tool tip shown in **14**A;

FIG. **15** shows an axial cross-section of the multi-layer ferromagnetic coated conductor surgical tool tip shown in FIG. **14**A;

FIG. **16** shows a cross-sectional view of a flattened side cylindrical geometry ferromagnetic coated conductor showing electromagnetic lines of flux;

FIG. **17** shows a closed conductor tip in accordance with another aspect of the present invention;

FIG. **18**A shows a single edge ferromagnetic coated conductor surgical tool tip in accordance with one aspect of the invention;

FIG. **18**B shows a double edge ferromagnetic coated conductor surgical tool tip;

FIG. **18**C shows a three wire ferromagnetic coated conductor surgical tool tip;

FIG. **18**D shows a receptacle for the tips shown in FIGS. **18**A through **18**C;

FIG. **19**A shows a normally cold cutting scalpel with alternate inductive ferromagnetic thermal function;

FIG. **19**B shows an alternate embodiment of a normally cold cutting scalpel with alternate inductive ferromagnetic thermal function;

FIG. **20**A shows a thermal surgical tool with a spatula shaped geometry;

FIG. **20**B shows a thermal surgical tool with a spatula shaped geometry in a forceps configuration;

FIG. **20**C shows a top view of the thermal surgical tool of FIG. **20**A with the ferromagnetic coated conductor upon the primary geometry;

FIG. **20**D shows a top view of the thermal surgical tool of FIG. **20**A with the ferromagnetic coated conductor embedded within the primary geometry;

FIG. **21**A shows a thermal surgical tool with a ball shaped geometry and horizontal winding;

FIG. **21**B shows an alternate embodiment of a thermal surgical tool with a ball shaped geometry and horseshoe configuration;

FIG. **21**C shows an alternate embodiment of a thermal surgical tool with a ball shaped geometry and vertical orientation;

FIG. **22**A shows a thermal surgical tool with a pointed geometry;

FIG. **22**B shows a thermal surgical tool with a pointed geometry in a forceps configuration;

FIG. **22**C shows a thermal surgical tool having two different activatable thermal zones;

FIG. **23**A shows a perspective view of a catheter having a coil of ferromagnetic coated conductor disposed around the tip of the catheter;

FIG. **23**B shows a perspective view of a ferromagnetic coated conductor surgical catheter tip;

FIG. **24** shows a side view of an alternate embodiment of a ferromagnetic coated conductor surgical catheter tip;

FIG. **25** shows an alternate embodiment of a ferromagnetic coated conductor surgical tool ferromagnetic tip disposed within an endoscope;

FIG. **26** shows a tissue ablation tool; and

FIG. **27** shows a thermal spectrum as related to tissue effects.

It will be appreciated that the drawings are illustrative and not limiting of the scope of the invention which is defined by the appended claims. The embodiments shown accomplish various aspects and objects of the invention. It is appreciated that it is not possible to clearly show each element and aspect of the invention in a single Figure, and as such, multiple figures are presented to separately illustrate the various details of the invention in greater clarity. Similarly, not every embodiment need accomplish all advantages of the present invention.

DETAILED DESCRIPTION

The invention and accompanying drawings will now be discussed in reference to the numerals provided therein so as to enable one skilled in the art to practice the present invention. The drawings and descriptions are exemplary of various aspects of the invention and are not intended to narrow the scope of the appended claims.

As used herein, the term “ferromagnetic,” “ferromagnet,” and “ferromagnetism” refers to any ferromagnetic-like material that is capable of producing heat via magnetic induction, including but not limited to ferromagnets and ferrimagnets.

Turning now to FIG. **1**, there is shown a perspective view of a thermal surgical tool system, generally indicated at **10**. As will be discussed in additional detail below, the thermal tool system preferably uses a ferromagnetic coated conductor to treat or destroy tissue (i.e. endothelial tissue welding, homeostasis, ablation, etc).

It will be appreciated that the thermal surgical tool uses heat to incise tissue and does not cut tissue in the sense of a sharp edge being drawn across the tissue as with a conventional scalpel. While the embodiments of the present invention could be made with a relatively sharp edge so as to form a cutting blade, such is not necessary as the heated coating discussed herein will separate tissue without the need for a cutting blade or sharp edge. However, for convenience, the term cutting is used when discussing separating tissue.

In the embodiment shown as thermal surgical tool system **10**, a control mechanism, such as a foot pedal **20** is used to control output energy produced by a power subsystem **30**. The energy from the power subsystem **30** may be sent via radio frequency (RF) or oscillating electrical energy along a cable **40** to a handheld surgical tool **50**, which contains a conductor **60** having a section thereof coated with a ferromagnetic coating **65**. The ferromagnetic coating **65** may transfer the electrical energy into available thermal energy via induction and corresponding hysteresis losses in the ferromagnetic material disposed around a conductor wire **66**. (While conductor wire is used for ease of reference, it will be appreciated that the conductor material need not be a wire and those skilled in the art will be familiar with multiple conductors which will work in light of the disclosure of the present invention).

Application of a magnetic field (or magnetizing) to the ferromagnetic coating may produce an open loop B-H curve (also known as an open hysteresis loop), resulting in hysteresis losses and the resultant thermal energy. Electrodeposited films, such as a nickel-iron coating like PERMALLOY™, may form an array of randomly aligned microcrystals, resulting in randomly aligned domains, which together may have an open loop hysteresis curve when a high frequency current is passed through the closely coupled conductor.

The RF energy may travel along the conductor’s surface in a manner known as the “skin effect”. The alternating RF current in the conductor’s surface produces an alternating magnetic field, which may excite the domains in the ferromagnetic coating **65** that is in close proximity to the surface of the conductor. As the domains realign with each oscillation of the current, hysteresis losses in the coating may cause inductive heating.

The RF conductor from the signal source up to and including the tip, may form a resonant circuit at a specific frequency (also known as a tuned circuit). Changes in the tip “detune” the circuit. Thus, should the ferromagnetic coating **65** or the conductor wire **66** become damaged, the circuit may likely become detuned. This detuning should reduce the efficiency of the heating of the ferromagnetic coating **65** such that the temperature will be substantially reduced. The reduced temperature should ensure little or no tissue damage after breakage.

A breakage or other fault may also be detected by a sensor. Interruptions to normal circuit operation may thus be detected and cause the surgical system to shut down. In one embodiment, current is monitored. If a sudden unexpected increase in current is detected, the system may shut down because the ferromagnetic coating may be no longer be dissipating the power it should. Similarly, impedance may be monitored and used as an indicator of a system fault.

It should be understood that the handheld surgical tool **50** may include indicia of the power being applied and may even include a mechanism for controlling the power. Thus, for example, a series of lights **52** could be used to indicate power level, or the handheld surgical tool **50** could include a switch, rotary dial, set of buttons, touchpad or slide **54** that communicates with the power source **30** to regulate power and thereby affect the temperature at the ferromagnetic coating **65** to having varying effects on tissue. These indicia may display the current status as represented by the power source and communicated to a user adjustable control by the power source. While the controls are shown on the foot pedal **20** or the handheld surgical tool **50**, they may also be included in the power subsystem **30** or even a separate control instrument. Safety features such as a button or touchpad that must be contacted to power the handheld surgical tool **50** may be employed, and may include a dead man's switch.

While the ferromagnetic coating **65** heats through induction, it also provides a temperature cap due to its Curie temperature. A Curie temperature is the temperature at which the material becomes paramagnetic, such that the alignment of each domain relative to the magnetic field decreases to such an extent that the magnetic properties of the coating are lost. When the material becomes paramagnetic, the heating caused by induction may be significantly reduced or even cease. This causes the temperature of the ferromagnetic material to stabilize around the Curie temperature if sufficient power is provided to reach the Curie temperature. Once the temperature has dropped below the Curie temperature, induction may again start causing heating of the material up to the Curie temperature. Thus, the temperature in the ferromagnetic coating may reach the Curie temperature during inductive heating with the application of sufficient power, but will not likely exceed the Curie temperature.

The thermal surgical tool system **10** allows the power output to be adjustable in order to adjust the temperature of the tool and its effect on tissue. This adjustability gives the surgeon precise control over the effects that may be achieved by the handheld surgical tool **50**. Tissue effects such as cutting, hemostasis, tissue welding, tissue vaporization and tissue carbonization occur at different temperatures. By using the foot pedal **20** (or some other user control) to adjust the power output, the surgeon (or other physician, etc.) can adjust the power delivered to the ferromagnetic coating **65** and consequently control the tissue effects to achieve a desired result.

Thermal power delivery can be controlled by varying the amplitude, frequency or duty cycle of the alternating current waveform, or alteration of the circuit to affect the standing wave driving the ferromagnetic coated conductor, which may be achieved by input received by the foot pedal **20**, the power subsystem **30**, or the controls on the handheld surgical tool **50**.

For example, it is known that different temperatures are desirable for inducing different effects on tissue. As will be explained in additional detail below, certain temperatures can be used for welding tissues, while other temperatures will induce cutting, tissue ablation and vaporization.

One advantage of the present invention is that it enables the surgeon to control power to the system, which ultimately affects the temperature at the ferromagnetic coating **65** which can be applied to the tissue. Power can be adjusted by multiple methods. Pulse width modulation can be used to change the amount of time the ferromagnetic coating **65** is being heated, thereby controlling the temperature. Amplitude modulation can be used to likewise control the power through the system and the ultimate temperature dynamics of the ferromagnetic coating **65**. As the RF conductor from the signal source to the tip, including the tip, may form a resonant circuit at a specific frequency (also known as a tuned circuit), changes in the tip "detune" the circuit. Thus, frequency modulation can be used to effectively temporarily detune the circuit and thereby ultimately control the temperature for tissue welding, cutting, etc. An exemplary circuit may use a phase locked loop or frequency synthesizer to adjust frequency.

Power to the system can be controlled by a regulating structure, such as, for example, the foot pedal **20**. The pedal may have set points which indicate to the surgeon the power which is being supplied. This can be accomplished, for example, by having a pedal which has five positions, with each position requiring more force. The change in force required will alert the surgeon to the temperature range that is being applied.

The power controller, such as a pedal, can also be used to send a signal to the surgeon as to the power level being applied at the ferromagnetic coating **65** or the energy available at the coating available for delivery to the tissue. This could be an auditory or visual indicator **22** which gives the surgeon a signal to indicate the power level. For example, if five power levels are provided, an auditory alarm may indicate the power level being applied. One chime for level or range 1, two chimes for level or range 2, three chimes for level or range 3, etc. Similarly, five distinct auditory signal tones could be used to indicate the five power levels.

Likewise the tool **50** could include indicia of the power being applied and could even include a mechanism for controlling the power. Thus, for example, a series of lights **52** could be used to indicate power level, or the tool **50** could include a switch, rotary dial, set of buttons, touchpad or slide **54** that communicates with the power source **30** to regulate power and thereby affect the temperature at the ferromagnetic coating **65** to having varying effects on tissue. While the controls are shown on the foot pedal **20** or the tool **50**, it may also be included in the power subsystem **30** or even a separate control instrument. Similarly, safety features such as a button or touchpad that must be contacted to power the tool **50** may be employed, such as a dead man's switch.

One additional advantage achieved by the inductive heating is that the ferromagnetic material can be heated to a cutting temperature in a small fraction of a second (typically as short as one quarter of a second). Additionally, because of the relatively low mass of the coating, the small thermal mass of the conductor, and the localization of the heating to a small region due to construction of the handheld surgical tool **50**, the material will also cool extremely rapidly (i.e. approximately one half of a second). This provides a surgeon with a precise thermal tool while reducing accidental tissue damage caused by touching tissue when the thermal tool is not activated.

It will be appreciated that the time period required to heat and cool the handheld surgical tool **50** will depend, in part, on the relative dimensions of the conductor **60** and the ferromagnetic coating **65** and the heat capacity of the structure of the surgical tool. For example, the above time periods for heating and cooling of the handheld surgical tool **50** can be achieved with a tungsten conductor having a diameter of about 0.375 mm and a ferromagnetic coating of a Nickel Iron alloy (such as NIRON™ available from Enthone, Inc. of West Haven, Conn.) about the tungsten conductor about 0.0375 mm thick and two centimeters long.

One advantage of the present invention is that a sharp edge is not needed. When power is not being supplied to the surgical tool, the tool will not inadvertently cut tissue of the patient or of the surgeon if it is dropped or mishandled. If power is not being supplied to the conductor wire **66** and coating **65**, the "cutting" portion of the tool may be touched without risk of injury. This is in sharp contrast to a cutting blade which may injure the patient or the surgeon if mishandled.

Other additions may also be placed on the handpiece in various locations. This may include a sensor stem **12** including a sensor to report temperature or a light to illuminate the surgical area.

Turning now to FIG. **2**, a perspective view of an alternate embodiment of a thermal surgical system **10** is shown. In FIG. **2**, the power source **30** is contained within the foot pedal **20**. Depending on the application and power required, the instrument may even be entirely battery powered for relatively low power applications. An alternate embodiment for low power requirements may include the battery, power adjustment and power delivery, all self-contained in the handle **51** of the handheld surgical tool **50**. Furthermore, a wireless communication module can be employed to send and receive information from the handheld surgical tool **50**, including status and control settings that would enable users to monitor system performance and alter power settings remotely from the handheld surgical tool **50** itself.

It is our understanding that this thermal solution may provide advantages over monopolar and bipolar electrical systems currently available because the thermal damage may remain very close to the ferromagnetic surface of the coated region, whereas monopolar and bipolar electrical tissue ablation may frequently cause tissue damage for a distance away from the point of contact. It is our understanding that this method may also overcome disadvantages of other thermal devices based upon resistive heating, which may require more time to heat and cool, and thus present greater patient risk, while potentially having higher power requirements at the point of heating.

Furthermore, the thin ferromagnetic coating **65**, disposed along a small segment of the conductor, may reduce the heating of other non-target material in the body, such as blood when working within the heart in atrial ablation—which can lead to complications if a clot is formed. The small thermal mass of the conductor wire **66**, and localization of the heating to a small region provided by the construction of the tool (i.e. ferromagnetic coating **65** and adjacent structures) provides a reduced thermal path for heat transfer in directions away from the location of the ferromagnetic coating **65**. This reduced thermal path may result in the precise application of heat at only the point desired. As this technology alone does not employ a spark or an arc like monopolar or bipolar technology, risks of ignition, such as by anesthetic gasses within or around the patient by sparks, are also reduced.

The thermal surgical tool system **10** may be used for a variety of therapeutic means—including sealing, "cutting" or separating tissue, coagulation, or vaporization of tissue. In one configuration, the thermal surgical tool system **10** may be used like a knife or sealer, wherein the surgeon is actively "cutting" or sealing tissue by movement of the ferromagnetic coating **65** through tissue. The thermal action of the embodiments disclosed here may have distinct advantages including substantial reduction, if not elimination, of deep tissue effects compared with those associated with monopolar and bipolar RF energy devices.

In another configuration, the ferromagnetic coated conductor **60** may be inserted into a lesion and set to a specific power delivery or variable power delivery based on monitored temperature. The thermal effects on the lesion and surrounding tissue may be monitored until the desired thermal effect is achieved or undesired effects are noticed. One advantage of the application of the ferromagnetic coated conductor is that it may be cost-effective compared to microwave or thermal laser modalities and avoids the undesired tissue effects of microwave lesion destruction. Thus, for example, a surgeon can insert the ferromagnetic coated conductor into a tumor or other tissue to be destroyed and precisely control the tissue damage that is created by activating the handheld surgical tool **50**.

Sensors may be used to monitor conditions of the handheld surgical tool **50**, the electrical path, or the tissue, such as an infrared detector on sensor stem **12**. For instance, the temperature of the device or tissue may be important in performing a procedure. A sensor in the form of a thermocouple, a junction of dissimilar metals, thermistor or other temperature sensor may detect or conduct a measurement of the temperature at or near the ferromagnetic coating **65** or tissue. The sensor may be part of the device, such as a thermocouple placed as a part of the conductor, along, adjacent or near the ferromagnetic coating, or separate from the handheld surgical tool **50**, such as a separate tip placed near the tissue or ferromagnetic coating **65**. Some sensors may measure indicators that correlate to a desired measurement, but are indirectly related. For example, temperatures may also be correlated with tissue effects, seen in FIG. **27**. Other useful conditions to monitor may include, but are not limited to, power delivered at the coating, tissue color, spectral absorption or reflection, conductor or tissue temperature range, tissue water content, proximity between the tissue and the conductor, tissue type, transferred heat, tissue status, impedance, resistance, return current, standing wave ratio (SWR), reflected power, reactance, center frequency, phase shift, voltage, current and visual feedback (i.e. a camera, fiberoptic or other visualization device).

The power supply may be configured to respond to sensor feedback. Depending on the desired application, the sensor may provide useful information in regulating or determining the output of the power supply. In one embodiment, the sensor sends a temperature reading to the power supply. The power supply may then increase or decrease power delivery to remain at or near the desired temperature range. In another embodiment, the sensor communicates a water content reading to the power supply during tissue ablation. If the water content drops below a desired level, the power supply may reduce the power setting as the tissue may be sufficiently dessicated. Other sensors may provide useful input that may call for other settings to change on the power supply, such as waveform, duration, timing or power settings.

The handheld surgical tool **50** may be configured for repeat sterilization or single patient uses. More complex devices may be useful for repeat sterilization, while more simple devices may be more useful for single patient use.

A method for treating or cutting tissue may include the steps of: selecting a surgical tool having a cutting edge and a conductor disposed adjacent the cutting edge, at least a portion of which is coated with a ferromagnetic material; cutting tissue with the cutting edge; and applying oscillating electrical energy to the conductor to heat the ferromagnetic material and thereby treating the cut tissue.

Optional steps of the method may include the steps of: causing hemostasis within the cut tissue; using the heated ferromagnetic material to incise tissue; or using the heated ferromagnetic material to cause vascular endothelial welding.

Referring now to FIG. **3**, a diagram of an embodiment of the adjustable thermal surgical tool system **10** is shown. The power delivery to the ferromagnetic coating **65** is controlled by a modulated high frequency waveform. The modulated waveform allows power delivery to be controlled in a manner that adjustably modifies, allows or blocks portions of the waveform based on the desired power delivery.

In FIG. **3**, an initial waveform **110** is passed through a modulator **120** receiving commands from a foot pedal **20**. The waveform is created by an oscillator **130** to the desired frequency, and modulated by the modulator **120**, which may include, but is not limited to, one or more of amplitude, frequency or duty cycle modulation, including a combination thereof. The resultant signal is then amplified by an amplifier **140**. The amplified signal is sent across a tuned cable **150**, meaning that the cable is tuned to provide a standing wave with maximum current and minimum voltage at the location of the ferromagnetic coating **65** of the handheld surgical tool **50**. Alternatively, the cable **150** may not be tuned, but a circuit may be placed in the handle **51** to impedance match the ferromagnetic coated conductor **60** as a load to the power source **30**.

The thermal surgical tool system **10** may be tuned by specifying the location of the ferromagnetic coating **65** with respect to the amplifier **140** (such as cable length) and tuning the high frequency signal to approximately a resonant standing wave such that current is maximized at the location of the ferromagnetic coating **65**.

It should be recognized that the surgical tool may operate in a dynamic environment. Thus when used herein, approximately a standing wave means that a circuit may be tuned such that the signal may be near an optimal standing wave but may not achieve it, may only achieve the wave for small amounts of time, or may successfully achieve a standing wave for longer periods of time. Similarly, any use of "standing wave" without the modifier of approximate should be understood to be approximate in the context of the thermal surgical tool.

One method for achieving such current maximization is to connect the ferromagnetic coated conductor **60** to a cable **150** that is effectively an odd multiple of one-quarter wavelengths in length and connected to the output of the amplifier **140**. The design of the circuit having a resonant standing wave is intended to optimize power delivery to the ferromagnetic coating. However, in one embodiment, the power source **30** could be positioned at the location of (or closely adjacent to) the ferromagnetic coating **65**, and tuning could be achieved with electrical components, all within a single handheld, battery-powered instrument. Alternatively, electrical components necessary for impedance matching can be located at the output stage of the amplifier **140**. Further, electrical components, such as a capacitor or inductor, can be connected in parallel or series to the ferromagnetic coated conductor **60** at the location of the connection of the conductor wire **66** to the cable **150**, in order to complete a resonant circuit.

Dynamic load issues can be caused by the interaction of the ferromagnetic coated conductor **60** with various tissues. These issues may be minimized by the standing current wave (or at least one standing wave or waveform) being maximized at the load location. Multiple different frequencies can be used, including frequencies from 5 megahertz to 24 gigahertz. It is currently believed that that a waveform, preferably between 40 megahertz to 928 megahertz is desirable.

In some regulated countries it may be preferable choose frequencies in the ISM (industrial, scientific and medical) bands such as bands with the center frequencies of 6.78 MHz, 13.56 MHz, 27.12 MHz, 40.68 MHz, 433.92 MHz, 915 MHz, 2.45 GHz, 5.80 GHz, 24.125 GHz, 61.25 GHz, 122.5 GHz, 245 GHz. In one embodiment, the oscillator **130** uses an ISM Band frequency of 40.68 MHz, a class E amplifier **140**, and a length of coaxial cable **150**, all of which may be optimized for power delivery to a ferromagnetic coated tungsten conductor **60** with a ferromagnetic coating **65** consisting of a thickness of between 0.05 micrometer and 500 micrometers, and preferably between 1 micrometer and 50 micrometers. A useful estimate may be to start the ferromagnetic coating thickness at 10% of the conductor diameter, and up to 5 cm long. However, the ferromagnetic coating may be disposed as far along the length or along multiple regions of the conductor as where heating may be desired. (The ferromagnetic coating **65** may be formed from a Nickel Iron (NiFe) alloy, such as NIRON™ from Enthone, Inc. of West Haven, Conn., or other ferromagnetic coatings, including Co, Fe, $FeOFe_2O_3$, $NiOFe_2O_3$, $CuOFe_2O_3$, $MgOFe_2O_3$, MnBi, Ni, MnSb, $MnOFe_2O_3$, $Y_3Fe_5O_{12}$, CrO_2, MnAs, Gd, Dy, EuO, magnetite, yttrium iron garnet, aluminum, PERMALLOY™, and zinc.)

The size of the conductor, size of the ferromagnetic coating, associated thicknesses, shape, primary geometry, composition, power supply and other attributes may be selected based on the type of procedure and surgeon preferences. For example, a brain surgeon may desire a small instrument in light handheld package designed for quick application within the brain, while an orthopedic surgeon may require a larger device with more available power for operation on muscle.

The conductor may be formed from copper, tungsten, titanium, stainless steel, platinum and other materials that may conduct electricity. Considerations for the conductor may include, but are not limited to mechanical strength, thermal expansion, thermal conductivity, electrical conduction/resistivity, rigidity, and flexibility. It may be desirable to form the conductor wire **66** of more than one material. Connection of two dissimilar metals may form a thermocouple. If the thermocouple were placed in the vicinity of or within the ferromagnetic coating, the thermocouple provides a temperature feedback mechanism for the device. Further, some conductors may have a resistivity that correlates to temperature, which may also be used to measure temperature.

The tuning of the power source **30** also reduces the amount of high frequency energy radiating into the patient to near zero, as voltage is low, and ideally zero, at the location of the ferromagnetic coating **65**. This is in contrast to monopolar devices, which require a grounding pad to be applied to the patient, or bipolar devices, both of which pass current through the tissue itself. The disadvantages of these effects are well known in the literature.

In many of these embodiments discussed herein, the combination of cable length, frequency, capacitance and inductance may also be used to adjust efficiency and tool geometry by tuning the power source **30** to deliver maximum power to the ferromagnetic coating **65**, and therefore, maximum heat to the tissue. A tuned system also provides for inherent safety benefits; if the conductor were to be damaged, the system would become detuned, causing the power delivery efficiency to drop, and may even shut down if monitored by an appropriate safety circuit.

The amount of power delivered to the patient tissue may be modified by several means to provide precise control of tissue effects. The power source **30** may incorporate a modulator **120** for power delivery as described above. Another embodiment uses modification of the magnetic field by altering the geometry of the conductor wire **66** and the ferromagnetic coating **65** through which it passes, such as would be caused by a magnet. Placement of the magnet nearby the ferromagnetic coating **65** would similarly alter the induction effect and thereby change the thermal effect.

Different forms of modulation may be used to control delivery of power. Pulse width modulation is based on the principle that the ferromagnetic coating acts as a thermal integrator. Amplitude modulation may control power delivery by altering a continuous waveform so that only the desired power is delivered. Frequency modulation may "detune the circuit" or change the standing wave ratio causing losses to occur in transmission such that the full power is not delivered to the load.

While modulation has been discussed as a method to control power delivery, other methods may be used to control power delivery. In one embodiment, the output power, and correspondingly the temperature, of the tool is controlled by tuning or detuning the drive circuit, including the conductor wire **66** and ferromagnetic coated conductor **60**.

A process of delivering power to a thermally adjustable tool may include the steps of: signal will have approximately a standing wave with maximum current and minimum voltage at a load, the load consisting of a ferromagnetic material coated on the conductor; delivering the oscillating electrical signal to the load; and causing the electrical signal to no longer be sent to the load.

The process may optionally include the steps of: providing a oscillating electrical signal between the frequencies of 5 megahertz and 24 gigahertz; or providing an oscillating electrical signal selected from the group of center frequencies of 6.78 MHz, 13.56 MHz, 27.12 MHz, 40.68 MHz, 433.92 MHz, 915 MHz, 2.45 GHz, 5.80 GHz, 24.125 GHz, 61.25 GHz, 122.5 GHz, 245 GHz.

A method of incising tissue may include the steps of: selecting a conductor having a ferromagnetic coating disposed on a portion thereof; disposing the ferromagnetic coating into contact with the tissue; and delivering an oscillating electrical signal to the conductor so as to heat the ferromagnetic coating and cut the tissue.

The method may optionally include the step of selecting a power output of the oscillating electrical signal. The power output may correspond to a temperature range at the ferromagnetic coating or a desired tissue effect. The temperature range may be selected for a corresponding tissue effect of cutting, hemostasis, vascular endothelial welding, tissue vaporization, tissue ablation and tissue carbonization.

An alternative method for incising tissue may include the steps of: selecting a conductor having a ferromagnetic coating disposed on a portion thereof, which is associated with a plug; placing the plug into a receptacle configured for power delivery; disposing the ferromagnetic coating into contact with the tissue; and delivering an oscillating electrical signal to the conductor through the plug so as to heat the ferromagnetic coating and incise the tissue.

The method may optionally include the steps of: removing the plug after use; communicating the characteristics of the conductor and ferromagnetic coating; accessing a computer chip within the plug; or communicating a resistor value corresponding to characteristics in a lookup table.

A method for performing surgery may include the steps of: selecting a load comprising a conductor with a ferromagnetic coating; delivering power to the conductor through oscillating electrical energy from a power source; and matching an impedance of the load to an impedance of the power source, also referred to herein as a generator.

The method may optionally include the steps of: changing the output impedance of the power source to match the load; altering the frequency of the oscillating electrical energy; adjusting the power source to achieve a standing wave in the oscillating electrical energy; maximizing current at the conductor; choosing components to achieve a standing wave at the conductor; or selecting a length of cable to connect the power source to the electrical conductor to achieve a standing wave at the conductor.

A method for treating tissue may include the steps of: selecting a conductor having a ferromagnetic coating disposed on a portion thereof; disposing the ferromagnetic coating into contact with the tissue; delivering an oscillating electrical signal to the conductor so as to heat the ferromagnetic coating and treat the tissue; and adjusting a user control to alter the power delivered.

A method for cutting may include the steps of: selecting a conductor, a portion of the conductor having a ferromagnetic coating disposed thereon; delivering an oscillating electrical signal to the conductor to cause hysteresis in the ferromagnetic coating and thereby heat the ferromagnetic coating; and applying the heated coating to a substance to be cut to thereby cut the substance.

Turning now to FIG. **4**A, a thermal surgical tool system **10** with connectors which attach to opposing first and second ends of a wire conductor is shown. The conductors as shown in FIG. **4**A may be formed by heat prevention terminals **280**, such as crimp connectors that provide thermal isolation. One or more heat sinks **282**, and wireless communication devices **286** may also be included. The wire conductor **220** may be connected to the handheld surgical tool **50** by terminals **280** and/or a heat sink **282** at opposing first and second ends of the conductor. Portions of the conductor may extend into the handle into terminals, while the ferromagnetic coating portion of the conductor may extend beyond the handle. The terminals **280** may have a poor thermal conductance such that the terminals **280** reduce the heat transfer from the conductor into the handheld surgical tool **50**. In contrast, the heat sink **282** may draw any residual heat from the terminals **280** and dissipate the heat into other mediums, including the air. Connectors and connections may also be achieved by wire bonding, spot and other welding, in addition to crimping.

Preventing thermal spread may be desirable because the other heated portions of the handheld surgical tool **50** may cause undesired burns, even to the operator of the handheld surgical tool **50**. In one embodiment, terminals **280** are used to conduct the electric current, but prevent or reduce thermal conduction beyond the ferromagnetic coated conductor.

The thermal surgical tool may also communicate wirelessly. In one embodiment, the user interface for monitoring and adjusting power levels may be housed in a remote, wirelessly coupled device **284**. The wirelessly coupled device may communicate with a wireless module **286** contained within the thermal surgical tool system **10**, including the handheld surgical tool **50**, the control system (such as footpedal **20**), and/or the power subsystem **30**. By housing the control interface and display in a separate device, the cost of the handheld surgical tool **50** portion may be decreased. Similarly, the external device may be equipped with more processing power, storage and, consequently, better control and data analysis algorithms.

Turning now to FIG. **4**B, a thermal surgical tool system with impedance matching network is shown. The impedance matching network may match the output impedance of the signal source to the input impedance of the load. This impedance matching may aid in maximizing power and minimizing reflections from the load.

In one embodiment, the impedance matching network may be a balun **281**. This may aid in power transfer as the balun **281** may match the impedance of the ferromagnetic coated conductor terminals **287** to the amplifier cable terminals **283** (shown here as a coaxial cable connection). In such a configuration, some baluns may be able to act as a heat sink and provide thermal isolation to prevent thermal spread from the thermal energy at the ferromagnetic coating **65** transferred by the wire conductor **220** to terminals **287**. The appropriate matching circuitry may also be placed on a ceramic substrate to further sink heat away or isolate heat away from the rest of the system, depending on the composition of the substrate.

It should be recognized that these elements discussed in FIGS. **4**A and **4**B can be used in conjunction with any of the embodiments shown herein.

Turning now to FIG. **5**A, a longitudinal cross section of the ferromagnetic coated conductor is shown. As an alternating current **67** is passed through conductor **66**, a time varying magnetic field **68** is induced around conductor **66**. The time varying magnetic field **68** is resisted by the ferromagnetic coating **65**, causing the ferromagnetic coating **65** to dissipate the inductive resistance to the time varying magnetic field **68** as heat. Should the ferromagnetic coating **65** reach its Curie point, the magnetic resistive properties of ferromagnetic coating **65** become substantially reduced, resulting in substantially decreased resistance to time varying magnetic field **68**. As there is very little mass to the ferromagnetic coating **65**, the magnetic field causes the ferromagnetic coating **65** to quickly heat. Similarly, the ferromagnetic coating **65** is small in mass compared to conductor **66** and therefore heat will quickly dissipate therefrom due to thermal transfer from the hot ferromagnetic coating **65** to the cooler and larger conductor **66**, as well as from the ferromagnetic coating **65** to the surrounding environment.

As is also evident from FIG. **5**A, the ferromagnetic coating may be between a first section (or proximal portion) and a second section (or distal portion) of the conductor. This may provide the advantage of limiting the active heating to a small area, instead of the entire conductor. A power supply may also connect to the first and second section to include the ferromagnetic coating within a circuit providing power.

A method of using the surgical tool may include the steps of: selecting a conductor and plating a ferromagnetic coating upon the conductor.

Optional steps to the method may include: selecting a size of a conductor having a ferromagnetic coating disposed on a portion thereof according to a desired procedure; selecting a thermal mass of a conductor having a ferromagnetic coating disposed on a portion thereof according to a desired procedure; selecting a conductor from the group of loop, solid loop, square, pointed, hook and angled; configuring the oscillating electrical signal to heat the coating to between 37 and 600 degrees Centigrade; configuring the oscillating electrical signal to heat the coating to between 40 and 500 degrees Centigrade; causing the coating to heat to between about 58-62 degrees Centigrade to cause vascular endothelial welding; causing the coating to heat to between about 70-80 degrees Centigrade to promote tissue hemostasis; causing the coating to heat to between about 80-200 degrees Centigrade to promote tissue searing and sealing; causing the coating to heat to between about 200-400 degrees Centigrade to create tissue incisions; or causing the coating to heat to between about 400-500 degrees Centigrade to cause tissue ablation and vaporization. Treatment may include incising tissue, causing hemostasis, ablating tissue, or vascular endothelial welding.

Turning now to FIG. **5**B, an electrical equivalent representation of a FIG. **5**A's ferromagnetic coated conductor is shown. The ferromagnetic coating is represented as a transformer **72** with a dynamic resistance **74**. The inductance of the ferromagnetic coated conductor varies based on the current passing through the conductor. At a low operating frequency, the inductance of the coating will have a small impact. At a high operating frequency, inductance of the coating will have greater effect. Further, different ferromagnetic coated conductor tip configurations will have different impedance characteristics. Therefore, it is necessary to provide a means to match the amplifier output to loads having different impedances.

A variety of means are available to achieve desired impedance matching. A continuously adjustable matching network may change the matching impedance as the load changes, seeking to keep it optimal for power transfer to the load. Thus, the generator may always have optimal power transfer to the load through the network. This may include adjusting capacitance, inductance or frequency of the network.

An advantageous design of the instrument is to employ minimal power levels from the amplifier necessary to achieve the desired therapeutic heating range. Continuous monitoring of signal characteristics, such as return current, standing wave ratio (SWR) or reflected power, become practical electrical methods both to maintain temporal heating and cooling properties and to achieve the desired temperature within a fraction of a second.

In one embodiment, SWR is monitored. By monitoring and retuning to optimize SWR, power transfer can be optimized for various ferromagnetic coated conductor tips.

Instead of measuring load characteristics, the load may be pre-characterized. Thus, the output impedance of the amplifier may be caused to change based on predicted characteristics of the load found in prior measurements. In one embodiment shown in FIG. **5**C, the handle **50** or handpiece cable connector may have a receptacle **51** which may match a plug **271** with a ferromagnetic coated conductor **220**. The system may include a load prediction module **269** configured to predict the load characteristics of the electrical conductor with the ferromagnetic coating. The plug may contain information identifying the predicted load characteristics of the ferromagnetic coated conductor attached to the plug in a data module or computer chip **273**. The data module may then communicate the characterization to the generator or generator control. The load prediction module **269** is further configured to use the predicted load characteristics to predict the necessary power output to achieve a desired temperature. Thus the system may predict and match the load characteristics by the information contained within the plug. This information may further aid the system in predicting output power to temperature correlations. Similar matching can be achieved with a plug that contains an electrical component **277**, such as a resistor, that is correlated and used to identify the configuration of the ferromagnetic coated conductor. In this case, the generator circuit would read the value of the resistor that identifies the ferromagnetic coated conductor and automatically adjusts drive settings. The plug **271** may also comprise a temperature sensor **279** proximate to the ferromagnetic coating. The plug or connector may also be configured for single use.

Instead of a generator having variable tuning, a driver having fixed output impedance may be employed to drive ferromagnetic coated conductor tips having input impedances that are properly matched for optimal power transfer. Because this matching network is static, it can be constructed in a variety of ways. One particularly simple method is to use a designated, fixed length of cable between the generator and the load, placing the load at the optimal point where maximum power can be transferred. This approach requires more design effort for the surgical tool but ultimately creates a physically simpler generator—that is, fewer parts and a less expensive system to build. Further, a balun may be used for impedance matching as described above. These approaches may effectively maintain a constant current through the ferromagnetic coated conductor.

In applications where the thermal load is dynamic, due to the changing thermal conductivity of the surgical environment, a variety of means are available to achieve and maintain desired tissue effects. A continuously adjustable amplifier may change the power level as the thermal load changes, seeking to keep power transfer to the load adequate to achieve and maintain desired tissue effects. Through the previously described impedance matching network, the generator may always have optimal power transfer to the load through the network. If the changing thermal load changes the impedance of the ferromagnetic coated conductor, the power output of the ferromagnetic coating may be maintained by continuously adjusting the network driving the ferromagnetic material, as its load, in order to keep the material in an optimized heating mode. This may include adjusting capacitance, inductance or frequency of the network.

Methods similar to those described above for driving ferromagnetic coated conductors representing loads of varying impedance can be used to adapt to individual ferromagnetic coated conductors which change their impedance in changing surgical environments, including interaction with various tissues and liquids. Continuous monitoring of signal characteristics, such as return current, standing wave ratio (SWR) or reflected power, become practical electrical methods both to maintain temporal heating and cooling properties and to achieve the desired temperature within a fraction of a second.

In one embodiment, SWR is monitored. By monitoring and retuning to optimize SWR, power transfer can be optimized as the surgical environment and heat transfer away from the ferromagnetic coating changes. Rapid retuning, which may be practically achievable at least at 10 Hz, allows dynamic responsiveness for temperature as the surgical device is moved in and out of the wet surgical environment and into the air.

It should be appreciated that while the figures show a solid circular cross-section, the conductor cross-section may have various geometries. For instance, the conductor may be a hollow tubing such that it reduces thermal mass. Whether solid or hollow, the conductor may also be shaped such that it has an oval, triangular, square or rectangular cross-section.

Turning now to FIG. **6**, a close-up, longitudinal cross-sectional view of a single layer cutting tip with a thermal insulator **310** is shown. A layer of thermal insulator **310** may be placed between the ferromagnetic coating **65** and the conductor **66**. Putting a layer of thermal insulator **310** may aid in the quick heating and cool-down (also known as thermal response time) of the tool by reducing the thermal mass by limiting the heat transfer to the conductor **66**.

The thickness and composition of the thermal insulator may be adjusted to change the power delivery and thermal response time characteristics to a desired application. A thicker coating of thermal insulator **310** may better insulate the conductor **66** from the ferromagnetic coating **65**, but may require an increased power compared with a thinner coating of thermal insulator **310** in order to induce a magnetic field sufficient to cause the ferromagnetic coating to heat.

In FIGS. **7**A-**7**G a plurality of embodiments are shown in which the surgical tip **210** is a tool which includes a wire conductor **220** which has a portion of its length coated with a relatively thin layer of ferromagnetic coating **65**. As shown in FIGS. **7**A-**7**G, the ferromagnetic coating **65** may be a circumferential coating around a wire conductor **220**. When the wire conductor **220** is excited by a high frequency oscillator, the ferromagnetic coating **65** will heat through induction according to the power delivered, with an absolute limit provided by its Curie temperature. Because of the small thickness of ferromagnetic coating **65** and the tuned efficiency of high frequency electrical conduction of the wire at the position of the ferromagnetic coating **65**, the ferromagnetic coating **65** will heat very quickly (i.e. a small fraction of a second) when the current is directed through the wire conductor **220**, and cool down quickly (i.e. a fraction of a second) when the current is stopped.

Turning now to FIGS. **7**A, **7**B, **7**C, **7**D, **7**E, **7**F AND **7**G, ferromagnetic coated conductor surgical tips **210***a*, **210***b*, **210***c*, **210***d*, **210***e*, **210***f* and **210***g* are shown. In each of these embodiments, a portion of wire conductor **220** is bent and coated with ferromagnetic coating **65** such that the ferromagnetic coating **65** is only exposed to tissue where the desired heating is to occur. FIGS. **7**A and **7**B are loop shapes that can be used for tissue cutting or excision, depending upon the orientation of the tool to the tissue. FIG. **7**A shows a rounded geometry, while FIG. **7**B shows a squared geometry. FIG. **7**C shows a pointed geometry for heated tip applications that can be made very small because the process of tissue dissection, ablation, and hemostasis requires only a small contact point. FIG. **7**D shows an asymmetric tool with a loop geometry, where the ferromagnetic coating **65** is only disposed on one side of the tool. FIG. **7**E shows a hook geometry where the ferromagnetic coating **65** is disposed on the concave portion of the hook. FIG. **7**F shows a hook geometry where the ferromagnetic coating **65** is disposed on the convex portion of the hook. FIG. **7**G shows an angled geometry, which may be used in similar situations as a scalpel. Use of these various geometries of ferromagnetic coating **65** upon a wire conductor **220** may allow the surgical tip to act very precisely when active and to be atraumatic when non-active.

In one representative embodiment, the electrical conductor may have a diameter of 0.01 millimeter to 1 millimeter and preferably 0.125 to 0.5 millimeters. The electrical conductor may be tungsten, copper, other metals and conductive non-metals, or a combination such as two dissimilar metals joined to also form a thermocouple for temperature measurement. The electrical conductor may also be a thin coating of conductor, such as copper, dispersed around a non-metallic rod, fiber or tube, such as glass or high-temperature plastic, and the conductive material, in-turn, may be coated with a thin layer of ferromagnetic material. The magnetic film forms a closed magnetic path around the electrically conductive wire. The thin magnetic film may have a thickness about 0.01-50% and preferably about 0.1% to 20% of the cross-sectional diameter of the wire. Due to the close proximity of the coating to the wire, a small current can produce high magnetic fields in the coating and result in significant temperatures. Since the magnetic permeability of this film is high and it is tightly coupled to the electrical conductor, low levels of current can result in significant hysteresis losses.

It is therefore possible to operate at high frequencies with low alternating current levels to achieve rapid inductive heating up to the Curie point. The same minimal thermal mass allows rapid decay of heat into tissue and/or the conductor with cessation of current. The tool, having low thermal mass, provides a rapid means for temperature regulation across a therapeutic range between about 37 degrees Celsius and 600 degrees Celsius, and preferably between 40 and 500 degrees Celsius.

While Curie point has been previously described as a temperature cap, instead, here a material with a Curie point beyond the anticipated therapeutic need may be selected and the temperature can be regulated below the Curie point.

While some tip geometries are shown in FIGS. **7**A through **7**G, it is anticipated that multiple different geometries of the ferromagnetic coated conductor **60** may be used.

Turning now to FIG. **8**, a cut-away view of a snare **350** in a retracted position is shown. A ferromagnetic coating is placed on a conductor to form a snare loop **355** and then placed within a sheath **360**. While retracted, the snare loop **355** may rest within a sheath **360** (or some other applicator, including a tube, ring or other geometry designed to reduce the width of the snare when retracted). The sheath **360** compresses the snare loop **355** within its hollow body. The sheath **360** may then be inserted into a cavity where the target tissue may be present. Once the sheath **360** reaches the desired location, the snare loop **355** may be extended outside the sheath **360**, and end up deployed similar to FIG. **9**A. In one embodiment, the conductor **365** may be pushed or pulled to cause extension and retraction of the snare loop **355**.

Turning now to FIG. **9**A a side view of a snare **350** in an extended position is shown. Once extended, the snare loop **355** may be used in several different ways. In one embodiment, the snare loop **355** may be placed substantially around the target tissue, such that the tissue is within the snare loop **355**. The ferromagnetic coating may then be caused to be inductively heated as discussed above. The snare loop **355** is then retracted back into the sheath **360** such that the target tissue is separated and removed from tissue adjacent the target tissue. The desired temperature range or power level may be selected for hemostasis, increased tissue separation effectiveness or other desired setting. For example, in one embodiment, the snare **350** is configured for nasal cavity polyp removal.

In another use, the snare **350** may be configured for tissue destruction. Once within the desired cavity, the snare may be extended such that a portion of the snare loop **355** touches the target tissue. The snare loop **355** may then be inductively heated such that a desired tissue effect occurs. For example, in one embodiment, the sheath may be placed near or in the heart and the snare loop **355** inductively heated to cause an interruption of abnormal areas of conduction in the heart, such as in atrial ablation.

Turning now to FIG. **9**B, an alternate embodiment of a snare **351** is shown. The applicator may be a ring **361** instead of a sheath as in FIG. **9**A. Similar to the sheath, the ring **361** may be used to force the loop into an elongated position. Various devices could be used to hold the ring in place during use.

A method of separating tissue may include the steps of: selecting a conductor having a ferromagnetic coating disposed on a portion thereof; placing the portion of the conductor having the ferromagnetic coating within a tube; inserting the tube into a cavity; deploying the portion of the conductor having the ferromagnetic coating within the cavity; and delivering an oscillating electrical signal to the conductor so as to heat the ferromagnetic coating while the heated ferromagnetic coating is in contact with a target tissue.

Optional steps may include: deploying step further comprises placing the ferromagnetic coating substantially around the target tissue; retracting the ferromagnetic coating portion of the conductor into the tube; causing hemostasis in the target tissue; forming the conductor into a bent geometry such that a portion of the conductor remains within the tube; and touching a ferromagnetic covered portion of the bent geometry to the target tissue.

A method of removing tissue may include the steps of: selecting a conductor having at least one portion having a ferromagnetic conductor disposed thereon; and placing the ferromagnetic conductor around at least a portion of the tissue and pulling the ferromagnetic conductor into contact with the tissue so that the ferromagnetic conductor cuts the tissue.

Optional steps may include: using a conductor having a plurality of ferromagnetic conductors in an array or passing an oscillating electrical signal through the conductor while the ferromagnetic material is in contact with the tissue.

Turning now to FIG. **10**A, a close-up view of a cutting tip with a loop geometry and linear array of coatings is shown. While the above embodiments have disclosed a continuous ferromagnetic coating on a conductor, in another embodiment, there are more than one coating separated by gaps on a single conductor. This is termed a linear array of ferromagnetic elements (an example of a parallel array of ferromagnetic elements can be seen in FIGS. **18**A-**18**C).

In one embodiment, a loop geometry **270***a* may have multiple ferromagnetic coatings **65**, **65'**, and **65"** which are separated by gaps on a wire conductor **220**. In another embodiment shown in FIG. **10**B, a close up view of a cutting tip with an alternate hook geometry **270***b* and linear array of ferromagnetic coatings **65** and **65'** is shown on a wire conductor **220**. The linear array may include the advantage of allowing flexibility in building a desired thermal geometry.

The conductor **220** which may be formed of an alloy having shape memory, such as Nitinol (nickel titanium alloy). A Nitinol or other shape memory alloy conductor can be bent into one shape at one temperature, and then return to its original shape when heated above is its transformation temperature. Thus, a physician could deform it for a particular use at a lower temperature and then use the ferromagnetic coating to heat the conductor to return it to its original configuration. For example, a shape memory alloy conductor could be used to form a snare which changes shape when heated. Likewise, a serpentine shape conductor can be made of Nitinol or other shape memory alloy to have one shape during use at a given temperature and a second shape at a higher temperature. Another example would be for a conductor which would change shape when heated to expel itself from a catheter or endoscope, and then enable retraction when cooled.

In another embodiment, the ferromagnetic coatings may be formed in such a way that an individual coating among the linear array may receive more power by tuning the oscillating electrical energy. The tuning may be accomplished by adjusting the frequency and/or load matching performed by the power source to specific ferromagnetic coatings.

Frequency response of individual coatings may be affected by altering the physical characteristics of the individual coatings. These physical characteristics may include composition, thickness, length and proximity to other coatings. By altering the physical characteristics of each coating, the individual coatings may consume more power at an optimum frequency for that coating. Other coatings may dissipate less or no power at the same frequency. Thus it may be possible to address individual elements according to the frequency output by the generator.

Turning now to FIG. **11**, a cut-away view of a snare tool **370** with a linear array of coatings in a retracted position is shown. In some embodiments, some ferromagnetic coatings may lack the elasticity to effectively bend into a retracted position. Therefore, individual coating segments **375** may be separated by gaps **380** such that the conductor **365** may be flexed while the coating segments **375** may remain rigid.

Similarly, the snare tool **370** may be extended, as seen in FIG. **12**. The gaps **380** between the coating segments **375** may be adjusted such that the heating effect will be similar in the gaps **380** as the coating segments. Thus, the snare tool **370** with linear array may act similar to the snare with flexible coating in FIGS. **8** and **9**.

Turning now to FIG. **13**, a cross-sectional view of a single layer cutting tip in the ferromagnetic-coated region is shown.

The ferromagnetic coating **65** is disposed over a wire conductor **220**. The ferromagnetic coating **65** provides several advantages. First, the ferromagnetic coating **65** is less fragile when subjected to thermal stress than ferrite beads, which have a tendency to crack when heated and then immersed in liquid. The ferromagnetic coated conductor **60** has been observed to survive repeated liquid immersion without damage. Further, the ferromagnetic coating **65** has a quick heating and quick cooling quality. This is likely because of the small amount of ferromagnetic coating **65** that is acted upon by the magnetic field, such that the power is concentrated over a small area. The quick cooling is likely because of the small amount of thermal mass that is active during the heating. Also, the composition of the ferromagnetic coating **65** may be altered to achieve a different Curie temperature, which would provide a maximum self-limiting thermal ceiling attribute to the device.

Turning now to FIGS. **14**A, **14**B and **15**, a multilayer surgical tool tip is shown. A cross section of **14**A along the **221** line may result in FIG. **14**B which shows alternating layers of wire conductor **220** and **220'** and ferromagnetic coating **65** and **65'**. Heating capacity may be increased by layering thin layers of alternating conductor **220** and **220'** material and ferromagnetic coating **65** and **65'**, while still maintaining quick heating and cooling advantages. FIG. **15** shows an axial cross-sectional view from FIG. **14**A along the **390** line. The alternating layers of conductor **220** and **220'**, and ferromagnetic coating **65** and **65'** may also be seen.

Turning now to FIG. **16**, a flattened side cylindrical geometry is shown. The flat surface **180** can be manufactured to cause a thin plating **182** of ferromagnetic coating on the conductor **66** relative to the thicker plating around the rest of the conductor **66**. This thin plating **182** may result in selective first onset heating in this flat surface **180**. Inductive heating may be proportional to flux density within the magnetically permeable coating. In one embodiment, an asymmetrically thinned coating has a small cross sectional thickness and will generate higher hysteresis losses in the form of heat. Thus, a therapeutic temperature may be achieved with yet lower power at the flat surface **180** with higher flux density **192** compared to a cooler opposite side with a diminished flux density **190**. An advantage is that fast temporal response and distributed optimal heating at the tissue interface may be enhanced.

Turning now to FIG. **17**, the ferromagnetic coating **65** may also be configured to focus the temperature increase on the outside of the ferromagnetic coating **65**, further reducing the time needed to cool the ferromagnetic coating **65** in a relatively high power application. An example of such a configuration is shown in FIG. **17**, wherein the fields generated by the current flow **230** and **230'** (the arrows) may have a cancelling effect with respect to each other within the ferromagnetic coating **65**, keeping the ferromagnetic material between the looped conductor **441** cooler than the ferromagnetic material at the perimeter.

Turning now to FIGS. **18**A-**18**D, several surgical tip **194** geometries are demonstrated. In FIG. **18**A, a surgical tip **194*a*** with a single small diameter electrically conductive wire plated with the thin film magnetic material **196** is shown. In FIG. **18**B, the surgical tip **194*b*** with two small diameter electrically conductive wires plated with the thin film magnetic material **196'** is shown. In FIG. **18**C, a surgical tip **194*c*** with three small diameter electrically conductive wires plated with the thin film magnetic material **196"** are shown. It is thus contemplated that a tip geometry may consist of a plurality of small diameter electrically conductive wires plated with the thin film magnetic material. Such a design maintains the temporal heat responsiveness (rapid onset, rapid offset) essential to the dynamic surgical environment due to minimal mass of the ferromagnetic coated conductor. It is thus possible to configure a flat tine with two or more spaced wires as a practical monothermal or multithermal tool. Further, the tips **194*a***, **194*b*** and **194*c*** may also be exchangeable as seen in FIG. **18**D, which has a receptacle **198** for the tips **194** in FIGS. **18**A-**18**C. It will be appreciated that the generator system may be configured to adjust the power jointly delivered to two or more of the conductors and that a user control (as shown in other figures) can be provided for that purpose.

The ferromagnetic coating **65** can be used to contact the tissue directly, or, a non-stick coating, such as TEFLON (PTFE), or similar material, could be applied over the ferromagnetic coating and conductor to prevent sticking to the tissue. Alternatively, the ferromagnetic coating could be coated with another material, such as gold, to improve biocompatibility, and/or polished, to reduce drag force when drawing through tissue. The ferromagnetic coating could also be coated by a thermally-conductive material to improve heat transfer. In fact, a single coating may be selected to have multiple desirable properties.

Turning now to FIGS. **19** to **22**, the ferromagnetic coated conductor may be attached to a primary geometry. The primary geometry may provide an attachment surface or an internal site for the conductor with a ferromagnetic coating. Thus the advantages of the ferromagnetic coating on a conductor may be combined with the advantages of the primary geometry and its corresponding material. The primary geometry may be selected for various reasons, including but not limited to, material strength, rigidity, heat conduction, resistance to thermal heat transfer, surface area, or additional functionality.

As used herein, a primary geometry means a structure to which a ferromagnetic coated conductor may be attached and which defines the shape of the tool. For example, a primary geometry could be a scalpel, tines of forceps, the face of a spatula, or a ball shape at the end of a probe. The conductor geometry, therefore, may be disposed upon the primary geometry, may extend through a hole in the primary geometry, and/or be embedded in the primary geometry. For example, a primary geometry may be a scalpel, while the conductor geometry may be the serpentine shape of a ferromagnetic coated wire upon the primary geometry.

Turning now to FIGS. **19**A and **19**B, a cold cutting scalpel **223** with alternate inductive ferromagnetic thermal function is shown. The cold cutting scalpel **223** may be used for cutting through the application of a blade having a cutting edge and having a secondary thermal function activated when required, such as for coagulation. In the embodiments shown in FIGS. **19**A and **19**B, this is achieved by placing a ferromagnetic coated wire conductor **220** upon the side of a scalpel shaped primary geometry, which can cut or incise tissue without activation of the conductor or ferromagnetic coating **65**. The cold cutting scalpel **223** may be used classically to make incisions in tissue. However, if the patient begins to bleed, the cold cutting scalpel **223** operator may activate the ferromagnetic coated conductor and place the side of the cold cutting scalpel **223** (and correspondingly, the ferromagnetic coated conductor) upon the bleeding tissue. The thermal effect may then cause the tissue to seal and cease bleeding. After deactivation of the ferromagnetic coated conductor, the scalpel operator may then return to making incisions with the benefits of a cold cutting scalpel.

There are several advantages to use of such a cold cutting scalpel **223**. The dual-use tool does not require the cold cutting scalpel **223** operator to remove one tool and replace it with another, causing risk of further damage and delay. Due to the ferromagnetic coating **65**, the cold cutting scalpel **223** may also have a quick thermal response time (the heat-up and cool-down time) in the region of the ferromagnetic coating **65** such that the cold cutting scalpel **223** may be used on the targeted area and reduce waiting time. In cases where it may be desirable to heat the entire cold cutting scalpel, thermal response time may be further reduced by removing a center portion **222** of the blade, (as seen in FIG. **19**B), resulting in a non-contiguous portion of the blade that may occur between or adjacent to the conductor path. Removing the center portion **222** of the blade may further reduce the thermal mass and correspondingly the thermal response time.

In one embodiment, related to FIG. **19**B, the ferromagnetic coating may be limited to a part of the scalpel, such as the tip of the cold cutting scalpel **223**. This limiting would cause only the tip to heat, while the remaining portions of the primary geometry would remain at a lower temperature. This limiting of the heating to a portion of the primary geometry in proximity to the ferromagnetic coating may provide a higher degree of accuracy and usefulness in smaller spaces. Similarly, the ferromagnetic coated wire conductor **220** may form a pattern, such as a zigzag or serpentine pattern, across the surface of the cold cutting scalpel **223** to increase the heating coverage of the surface.

Scalpel effects may also be enhanced by the thermal effects of the ferromagnetic coated wire conductor **220**. In one embodiment, the scalpel may have multiple parts with different temperature ranges addressable to each part. For example, energy to the scalpel blade may be used to cut, while energy to the sides of the blade may be used to coagulate tissue walls. In another embodiment, the ferromagnetic coated wire conductor **220** may be activated to provide additional cutting ability when moving through more difficult tissue. In another embodiment, the ferromagnetic coated conductor may be activated to provide a more smooth cutting process in conjunction with the scalpel blade. A user control may be used to select a power setting to be delivered by a power source, which may be correlated with a desired temperature or tissue effect.

The power supply may address individual coatings and their associated conductors in a number of different ways. In one embodiment, the conductors have individual power lines, but share a common ground. In another embodiment, the conductors have individual power and ground lines. Another embodiment uses frequency modulation to address individual coatings. One digital embodiment uses three conductors. One conductor is used for communication about which coating should receive power, while the other two are the power and ground signals. An alternative digital circuit removes the communication circuit and instead sends a precursor identification signal on the power line such that the circuit can identify and direct the power to the correct circuit. In fact, these technologies are not mutually exclusive, but may be combined and used together. For example, the combination of circuits may be advantageous where some circuits require less power than other circuits.

Turning now to FIG. **20**A, a thermal surgical tool with a spatula shaped geometry is shown. The spatula **224** may have a ferromagnetic coating **65** on a wire conductor **220** that follows the perimeter of the spatula shape as shown. In an alternate embodiment, the ferromagnetic coated portion of the wire conductor **220** may form a pattern across the surface of the geometry such that the surface is more evenly covered by the ferromagnetic coated portion of the wire conductor **220**.

A spatula geometry may be useful for various tissue effects and procedures. In one embodiment, the spatula is used for hemostasis or tissue welding during surgery. After an incision has been made, if needed, the spatula may be applied to the incised tissue to achieve hemostasis or even tissue welding. In another embodiment, the spatula is pressed into tissue and thermal energy is used for tissue ablation.

Turning now to FIG. **20**B, the thermal surgical tool with a spatula shaped geometry is shown in forceps form. The spatula forceps **225** may be used in combination such that each spatula has a separate power control or the forceps may have a power control in common. In other embodiments, the forceps may also only be heated on one spatula of the forceps. Such a tool can be used to clamp vessels to stop blood flow, and then cause hemostasis and cutting of the vessels with heat.

Turning now to FIGS. **20**C and **20**D, a side view of FIG. **20**A is shown in two different embodiments. The ferromagnetic coating and wire conductor may be attached to the primary geometry in several ways. In one embodiment shown in **20**C, the ferromagnetic coating **65** and conductor may be attached to the surface of the primary geometry. Alternatively in **20**D, the ferromagnetic coating **65** and conductor may be embedded within the primary geometry. Depending upon the desired effect, the tools depicted in FIGS. **20**A, **20**B, **20**C and **20**D can be applied to tissue in such a manner that the side of the tool on which the ferromagnetic coated conductor **65** is located can contact the tissue, or the opposite side can be applied to the tissue.

Turning now to FIGS. **21**A, **21**B and **21**C, a thermal surgical tool with a ball shaped geometry is shown. In one embodiment, a horizontally wrapped ball **226** or a vertically wrapped ball **231** may be internally or externally wrapped with a wire conductor **220** with a ferromagnetic coating **65** as seen in FIG. **21**A and FIG. **21**C. In another embodiment, shown in FIG. **21**B, a ball geometry **227** may contain a wire conductor **220** with a ferromagnetic coating prepared in another shape, such as a horseshoe shape. In the embodiments, a ball-shaped heating element may be formed which can be used to coagulate or provide a therapeutic effect over a large surface area of tissue. The ball may also be effective in tissue ablation, as it may radiate thermal energy in most, if not all, directions.

Turning now to FIG. **22**A, a thermal surgical tool with a pointed geometry is shown. The pointed tool **228** may have a ferromagnetic coating **65** on a wire conductor **220** that follows the perimeter of the pointed tool shape as shown. In an alternate embodiment, the ferromagnetic coated portion of the wire conductor **220** may form a pattern across the point surface of the geometry such that the point surface is more evenly covered by the ferromagnetic coated portion of the wire conductor **220**. The pointed tool **228** may be particularly useful for making incisions that penetrate layers of tissue, providing a means for coagulation while cutting, such as coagulation of tissue around the site of trocar insertion for laparoscopic surgery.

Turning now to FIG. **22**B, the thermal surgical tool with a pointed geometry is shown in forceps form. The pointed forceps **229** may be used in combination such that each pointed geometry has a separate power control or the forceps may have a power control in common. Such a tool can be configured for achieving hemostasis and cutting in small vessel ligation.

While some primary geometries have been shown in singular form, the primary geometries may be used in combination. This may include two or more of the same primary geometry or differing primary geometries, including forceps applications. Each primary geometry may be commonly controlled for power or have separate power controls for each primary geometry. Furthermore, solid primary geometries may be altered similar to the scalpel primary geometry shown above such that portions of the primary geometries may be removed to reduce thermal mass and correspondingly, thermal response time.

While some of the primary geometries have been shown to have symmetrical construction, the primary geometries may have asymmetrical or directional construction such that only a portion of the primary geometry would be active. This may be accomplished by placing the ferromagnetic coating only on the portion of conductor wire residing on the area of the primary geometry desired to be active. For example, the spatula geometry may be configured to be active in one area if the ferromagnetic coated conductor is not symmetrically positioned on the spatula structure. This activation of only a part of the primary geometry may be further enhanced by providing a pattern, such as a zigzag or serpentine pattern, on the desired active portion of the geometry, such as a surface.

In another embodiment, a portion of the primary geometry may be activated. By using multiple conductors with a ferromagnetic coating **65** attached to different portions of a primary geometry, a portion of the primary geometry may be selectively activated. For example, a scalpel geometry **232** may be divided into a tip portion **234** and a face portion **236** as shown in FIG. **22**C. A scalpel operator may then choose whether to activate only the tip or the tip in conjunction with the face of the scalpel geometry, depending on the surface area desired. Similarly, in a forceps application, the forceps may be divided into inside and outside portions. If the forceps operator desires to remove something that may be surrounded by the forceps, such as a polyp, the internal portions may be activated while the external portions remain deactivated. If opposing sides of a void need to be sealed, the outside surfaces of the forceps may be activated.

By using multiple conductors with a ferromagnetic coating **65** attached to different portions of a primary geometry and separately controlled power sources, different portions of the primary geometry may be activated at the same time for different uses or effects. For example, an edge portion of a primary geometry may be activated for cutting while the blade portion may be activated for hemostasis.

A method of treating tissue may thus include the steps of: selecting a primary geometry having a conductor disposed thereon, the conductor having a ferromagnetic coating disposed on a portion thereof; disposing the ferromagnetic coating into contact with the tissue; and delivering an oscillating electrical signal to the conductor so as to heat the ferromagnetic coating and treat the tissue.

Optional steps of the method may include choosing a primary geometry selected from the group of scalpel, spatula, ball and pointed geometry. Treating of the tissue may include incising, causing hemostasis, ablating or vascular endothelial welding.

A method for tissue destruction may include the steps of selecting a conductor having a ferromagnetic coating disposed on a portion thereof; and delivering an oscillating electrical signal to the conductor so as to heat the ferromagnetic coating and destroy tissue.

Optional steps of the method may include monitoring the tissue and ceasing delivery of the oscillating electrical signal to the conductor when the desired tissue destruction has occurred or undesired tissue effects are to be prevented.

A method for forming a surgical instrument may include the steps of: selecting a primary geometry; coating a conductor with ferromagnetic material; and disposing the conductor on the primary geometry.

Optional steps of the method may include providing electrical connections on the conductor configured for receiving oscillating electrical energy.

Turning now to FIG. **23**A, a catheter **270** having a conductor **220** which is at least partially coated with ferromagnetic material disposed around the tip of the catheter is shown. Depending upon the therapeutic effect desired, the location of the coil of ferromagnetic coating **65** could instead be inside the catheter tip, or a single loop of ferromagnetic coated conductor having a circumference which approximates that of the catheter central channel **260** could be located at the end of the catheter tip.

In FIG. **23**B, another ferromagnetic coated catheter **270** is shown. While in some embodiments the conductor may be a wire, coil, or annular structure, a ferromagnetic coated catheter **270** could also be formed which would serve as an alternate conductor **250** with a ferromagnetic coating **65**. In this embodiment, the catheter could consist of two coaxial conductors, separated by an insulator. At the distal tip of the catheter **270**, a conductive coating can be applied such that a continuous electrical path is created by the coaxial conductors. The ferromagnetic coating can be dispersed about the external diameter surface near the distal tip of the catheter, as shown in FIG. **23**B, or, upon the end of the catheter, on the annular surface connecting the coaxial conductors. This would allow the ferromagnetic coated catheter **270** to perform other functions, such as irrigation, aspiration, sensing, or, to allow viewing access via optical fibers, through a central channel **260**, as is common in many interventional as well as open and minimally invasive surgical procedures. Furthermore, the central lumen of the catheter could be used to provide access to other sensing modalities, including, but not limited to, impedance and pH.

Turning now to FIG. **24**, a side view of an alternate embodiment of a ferromagnetic coated conductor surgical tool catheter tip **288** is shown. In one embodiment, the conductor may consist of a ferromagnetic coated conductor positioned on a substrate **285** forming a body with a central channel. The ferromagnetic coating may consist of a plated ferromagnetic coating **275** on top of a conductor **289**. The plating may be placed on the outside of the substrate **285** such that the thermal effects are directed externally. This may allow the catheter tip to apply thermal tissue effects to tissue walls.

In another embodiment, the inside of the substrate may contain the conductor **289** and ferromagnetic coating **275** such that the thermal effects are directed internally. An internal coating may allow delivery of a meltable solid to a desired area, such as in fallopian tube sealing and osteosynthesis applications.

Alternatively, the ferromagnetic coating **275** may surround the entrance to the central channel **260**, such that the thermal effects may be directed in front of the tip. Having the thermal energy be directed in front of the central channel **260** entrance may aid in taking a tissue sample or removal of material, such as a polyp.

The plating may be accomplished through multiple methods. The substrate **285** may be extruded, molded or formed from various materials including high temperature thermoplastic, glass, or other suitable substrate material. The actual plating may be accomplished through electroplating, electroless plating, vapor deposition, or etching, or some combination thereof. Thus through the plating process, a catheter tip

288 may be formed with a ferromagnetic coating **275** on a conductor **289** with a continuous path.

The catheter may also have multiple channels. One channel may be a deployment channel for the ferromagnetic coated conductor. Another channel may be used for one or more sensors or sources, or even each sensor or source in its own channel—such as a temperature sensor, illumination source and endoscope. Other channels may include delivery, irrigation or aspiration of substances, including those associated with treatment, such as in osteosynthesis or fallopian tube sealing. In fact, the ferromagnetic coating may aid in the melting of such substances and the coating may be directed at one or more specific channels rather than the catheter at large.

Turning now to FIG. **25**, an endoscope **240** with a viewing channel **262** of rod lens type or organized fiber bundle type aside a light emitting source **266** is shown. A loop coagulator/cutter **264** is shown which consists of the ferromagnetic coated conductor **65**. Such an adaptation is contemplated in snare applications such as colon polypectomy or sealing and cutting applications in various laparoscopic procedures. Other sensing modalities include near field tumor cell detection or infrared heat monitoring. Tool configurations similar to the described endoscope **240** can be embodied in tools that can be delivered to target tissue through the lumen of a catheter.

In one embodiment, tumor cells are caused to be tagged with materials that fluoresce when exposed to ultra-violet light. The endoscope **240** may contain a light source, **266**, and sensor or optics within the channel **262** that return the detected florescence. The ferromagnetic coating **65** portion of the endoscope **240** may then be directed at the tagged tissue for destruction.

In another embodiment, materials are deposited around target tissue or bone in a solidified condition. Once delivered, the materials are melted to conformation at the site by activation by the endoscope **240** described above. Examples of use of this embodiment include fallopian tube sealing and osteosynthesis. Furthermore, such materials could be removed by melting with the same or similar endoscope **240**, and aspirated through a central lumen of the endoscope **240**. In yet further applications, materials may be delivered in liquid form, and cured by a thermal heating process induced by the endoscope **240**.

Alternatively, the conductor may be part of a bundle of fibers. The fibers may be contained within a catheter or otherwise bundled together. The conductor may have a ferromagnetic coating, while the other fibers may have other purposes that include visual observation, sensing, aspiration, or irrigation.

A method of tissue ablation may include the steps of: selecting a catheter with a ferromagnetic covered conductor; causing the ferromagnetic covered conductor to touch tissue to be ablated; and delivering power to the ferromagnetic covered conductor.

Optional steps may include: directing the catheter to the tissue through the aid of an endoscope; selecting a ferromagnetic coated conductor disposed on the catheter; selecting a ferromagnetic coated conductor contained within the catheter; causing the ferromagnetic coated conductor to be deployed from the catheter; or touching the ferromagnetic coated conductor to the tissue to be ablated.

A method of delivering a substance into a body may include the steps of: selecting a catheter with a ferromagnetic coated conductor; placing a substance in the catheter; inserting the catheter into a body; and causing power to be sent to the ferromagnetic coated conductor.

Optional steps may include: selecting a substance for osteosynthesis; selecting a substance for fallopian tube sealing; or melting the substance in the catheter.

A method of treating tissue may include the steps of: selecting a catheter with a ferromagnetic coated conductor; placing the catheter in contact with tissue; and selecting a power setting. The temperature range may correspond to a temperature range or desired tissue effect. The desired tissue effect may be selected from the group of vascular endothelial welding, hemostasis, searing, sealing, incision, ablation, or vaporization. In fact, the power setting may correspond to a desired tissue effect.

Turning now to FIG. **26**, a tissue ablation tool **290** is shown. In typical applications of tissue ablation, an arm or tine **295** is inserted into undesired tissue. One or more tips **300** may be activated such that the tissue temperature is raised to a desired level for a desired amount of time. After the activation has succeeded in holding a temperature for a desired amount of time, or undesired effects are noticed, the one or more tips **300** may be deactivated and removed from the tissue.

In one embodiment, a conductor **220** may be contained in one or more arms or tines **295** with tips **300** that may contain ferromagnetic coatings **65**. The tips **300** may be inserted into tissue and temperature controlled until tissue destruction occurs or one or more undesired tissue effects occur. The tissue effects may be monitored through sensors in the tines **295** or externally.

Sensors may be placed in multiple ways. In one embodiment, the sensor is placed in the tine and away from a ferromagnetic coated tip **300**. In another embodiment, one tip **300** may have a ferromagnetic coating, while an alternate tip **300** may have no coating, but a sensor contained within. The sensor may monitor tissue effects or some other indicator indicative of the temperature of the ferromagnetic coated tip, properties of the associated tissue, or some desired characteristic and may include various sensors, cameras and remote imaging. In another embodiment, the temperature may be monitored through external imaging.

The sensor may thus form part of a feedback loop. By monitoring one or more tissue effects, the ablation tool may self-adjust power settings. This self-adjustment may allow the system to operate below the Curie point and still maintain a desired tissue effect and/or temperature range.

In the case where more than one tip **300** is used, the tips **300** with a ferromagnetic coating **65** may be individually controlled such that the thermal profile is concentrated in the desired area. This may also allow a second tine to monitor tissue effects, while a primary tine is used to perform the thermal function.

The power supply may individually address each tine. In one embodiment, the power supply monitors each tine for temperature. As tissue is destroyed, the water content of the tissue may decrease. As water content decreases, the tissue may not require the same amount of thermal energy. Thus, as tissue is destroyed, the power supply may monitor temperature and send less power or no power to tips **300** that show evidence of temperature spikes or changes.

While a diagram has been shown of a multi-tip tissue ablation tool in FIG. **26**, a single tissue ablation tool may be made in a configuration similar to FIG. **7**C.

Turning now to FIG. **27**, a temperature spectrum is disclosed. Tissue may react differently at different temperatures with a tissue treatment element (such as a ferromagnetic coated conductor) and thus temperature ranges will result in different treatments for tissue. Specific tissue treatments are somewhat variable due to inconsistencies including tissue type and patient differences. The following temperatures have been found to be useful. Vascular endothelial welding may be optimal at 58-62 degrees Centigrade. Tissue hemostasis without sticking may be achieved at 70-80 degrees Centigrade. At higher temperatures, tissue searing and sealing may occur more quickly, but coagulum may build-up on the instrument. Tissue incision may be achieved at 200 degrees Centigrade with some drag due to tissue adhesion at the edges. Tissue ablation and vaporization may occur rapidly in the 400-500 degree Centigrade range. Thus, by controlling the temperature the "treatment" of tissue which the device delivers can be controlled, be it vascular endothelial welding, tissue incision, hemostasis, tissue carbonization, tissue vaporization or tissue ablation. According to the spectrum disclosed above, power delivery settings corresponding to the desired temperature range may be included in the power delivery switch. In one embodiment, the foot pedal may have several stops that indicate to the surgeon the likely tip temperature range of the current setting.

Besides the advantages of uses in tissue, the surgical tool may also be self-cleaning. In one embodiment, when activated in air, the tool may achieve a temperature sufficient to carbonize or vaporize tissue debris.

It will be appreciated that the thermal surgical tool system in accordance with the present invention will have a wide variety of uses. Not only can it be used on humans, it can also be use to cut tissue of other animals, such as in the context of a veterinarian or simply cutting tissues or biomaterials, such as those used for implantation, into smaller pieces for other uses.

Certain embodiments of the surgical system may have broad application within surgery as well. A loop geometry may have advantages in cutting, coagulation and biopsy applications. A blade geometry may have advantages for cutting and hemostasis applications. The point geometry may have advantages in dissection and coagulation applications, and in particular, neurodissection and coagulation. However, the application of a geometry may be further configured and tailored to an application by diameter, length, material characteristics and other characteristics discussed above.

While the present invention has been described principally in the area of surgical tools and the treatment of live tissue (though it can be used on dead tissue as well), it will be understood that a tool made in accordance with the present invention and the methods discussed herein may have other uses. For example, a cutting tool could be formed for butchering meat. Whether the meat is fresh or frozen, the tool can be useful. For example, a cutting blade which is heated to a high temperature will cut through frozen meat. However, when power is no longer supplied, the "cutting" edge is safe to the touch. Likewise, cutting meat with a hemostasis setting would slightly sear the exterior of the meat, locking in juices. Other uses of the instruments discussed herein will be understood by those skill in the art in light of the present description.

There is thus disclosed an improved thermally adjustable surgical tool. It will be appreciated that numerous changes may be made to the present invention without departing from the scope of the claims.

What is claimed is:

1. A thermally adjustable surgical tool comprising:

an electrical conductor;

a ferromagnetic coating covering at least a part of the electrical conductor and being in electrical connectivity with the electrical conductor, the ferromagnetic coating having a thickness being between 0.5 μm and 500 μm;

a power supply disposed in communication with the electrical conductor and configured to produce an oscillating electrical energy to be delivered to the electrical conductor; and

wherein the power supply is configured to adjust the oscillating electrical energy.

2. The thermally adjustable surgical tool of claim **1**, further comprising a sensor configured to conduct a measurement.

3. The thermally adjustable surgical tool of claim **2**, wherein the sensor is configured to conduct the measurement proximate to the ferromagnetic coating.

4. The thermally adjustable surgical tool of claim **2**, wherein the power supply is configured to adjust the oscillating electrical energy to be delivered to the electrical conductor in response to the measurement of the sensor.

5. The thermally adjustable surgical tool of claim **2**, wherein the sensor comprises a temperature sensor proximate to the ferromagnetic coating.

6. The thermally adjustable surgical tool of claim **1**, further comprising a user control for adjusting the oscillating electrical energy to be delivered to the electrical conductor.

7. The thermally adjustable surgical tool of claim **1**, wherein the power supply is configured to respond to a load prediction module configured to calculate a predicted load characteristic of the electrical conductor with the ferromagnetic coating.

8. The thermally adjustable surgical tool of claim **1**, further comprising a handle and a plug, wherein the handle is configured to receive the plug and the plug is configured to receive the electrical conductor covered by the ferromagnetic coating, and wherein the plug includes a data module configured to communicate a predicted load characteristic of the electrical conductor to the power supply.

9. The thermally adjustable surgical tool of claim **8**, wherein the power supply is further configured to use the predicted load characteristic to adjust the oscillating electrical energy to be delivered to the electrical conductor to achieve a desired temperature of the ferromagnetic coating.

10. The thermally adjustable surgical tool of claim **8**, wherein the power supply is further configured to use the predicted load characteristic to adjust the oscillating electrical energy to be delivered to the electrical conductor.

11. The thermally adjustable surgical tool of claim **1**, wherein the thermally adjustable surgical tool is configured to impedance match the ferromagnetic coating covering at least the part of the electrical conductor.

12. The thermally adjustable surgical tool of claim **1**, further comprising an impedance matching circuit.

13. The thermally adjustable surgical tool of claim **1**, wherein the power supply is configured to adjust the oscillating electrical energy by at least one of: pulse width modulation, amplitude modulation, frequency modulation, and detuning an impedance matching circuit.

14. The thermally adjustable surgical tool of claim **13** wherein the thermally adjustable tool includes a handpiece and wherein the electrical conductor extends out of and returns to the handpiece to form a portion of a continuous circuit.

15. The thermally adjustable surgical tool of claim **13**, wherein the electrical conductor has a thickness and wherein the ferromagnetic coating thickness is less than 10 percent of the thickness of the electrical conductor.

16. The thermally adjustable surgical tool of claim **1**, wherein the electrical conductor has a thickness and wherein the thickness of the ferromagnetic coating is less than 10 percent of the thickness of the electrical conductor.

17. The thermally adjustable surgical tool of claim **1**, wherein the ferromagnetic coating thickness is between 1 μm and 50 μm.

18. A thermally adjustable surgical tool comprising:

an electrical conductor;

a ferromagnetic coating covering at least a part of and in electrically conductive communication with the electrical conductor;

at least one second electrical conductor and at least one second ferromagnetic coating disposed on and in electrically conductive communication with the at least one second electrical conductor, wherein the ferromagnetic coating and the at least one second ferromagnetic coating each have a thickness between 1 μm and 50 μm;

a power supply disposed in communication with the electrical conductor and the at least one second electrical conductor and configured to produce an oscillating electrical energy to be delivered to the electrical conductor and the at least one second electrical conductor; and

wherein the power supply is configured to adjust the oscillating electrical energy between a first energy level and a second energy level.

19. The thermally adjustable surgical tool of claim **18**, wherein the power supply is disposed in communication with the electrical conductor and the at least one second electrical conductor and is configured to produce the oscillating electrical energy to be delivered to the electrical conductor and the at least one second electrical conductor, and wherein the power supply is further configured to individually adjust the oscillating electrical energy to be delivered to at least one of the electrical conductor and the at least one second electrical conductor.

20. The thermally adjustable surgical tool of claim **18**, wherein the power supply is configured to produce the oscillating electrical energy to be jointly delivered to the electrical conductor and the at least one second electrical conductor, and wherein the power supply is further configured to adjust the oscillating electrical energy to be jointly delivered to the electrical conductor and the at least one second electrical conductor.

21. The thermally adjustable surgical tool of claim **18**, wherein at least one of the ferromagnetic coating and the at least one second ferromagnetic coating is configured to provide a first tissue effect and the other of the ferromagnetic coating and the at least one second ferromagnetic coating is configured to provide a different tissue effect when the oscillating electrical energy is passed through the electrical conductor and the at least one second electrical conductor.

22. The thermally adjustable surgical tool of claim **18** wherein the thermally adjustable tool includes a handpiece and wherein the electrical conductor and the at least one second electrical conductor extend out of and return to the handpiece.

23. A thermally adjustable surgical tool comprising:

a plurality of electrical conductors including at least a first electrical conductor and a second electrical conductor;

a plurality of ferromagnetic coatings disposed on and in electrically conductive communication with the plurality of the electrical conductors such that the first electrical conductor has a first ferromagnetic coating of the plurality of ferromagnetic coatings covering at least a portion of the first electrical conductor and the second electrical conductor has a second ferromagnetic coating of the plurality of ferromagnetic coatings covering at least a portion of the second electrical conductor, wherein at least one of the plurality of ferromagnetic coatings has a thickness between 1 μm and 50 μm;

a power supply disposed in communication with the plurality of electrical conductors configured to produce an oscillating electrical energy, and further configured to deliver the oscillating electrical energy to the plurality of electrical conductors; and

wherein the power supply is configured to adjust the oscillating electrical energy.

24. The thermally adjustable surgical tool of claim **23**, wherein the power supply is configured to adjust the oscillating electrical energy by at least one of: pulse width modulation, amplitude modulation, frequency modulation, and detuning an impedance matching circuit.

25. The thermally adjustable surgical tool of claim **23**, further comprising an impedance matching circuit.

26. A thermally adjustable surgical tool comprising:

an electrical conductor extending from a handpiece and returning to the handpiece so as to form a conductive loop;

a ferromagnetic coating covering at least a part of and in electrically conductive communication with the electrical conductor which extends from the hand piece;

a power supply disposed in communication with the electrical conductor and configured to produce an oscillating electrical energy having at least one signal characteristic, the oscillating electrical energy being configured to be delivered to the electrical conductor and the power supply being configured to receive the oscillating electrical energy back from the electrical conductor; and

wherein the power supply is configured to adjust the oscillating electrical energy between a first energy level and a second energy level; and wherein the thermally adjustable surgical tool is configured to monitor the at least one signal characteristic to achieve a desired temperature of the ferromagnetic coating.

27. The thermally adjustable surgical tool of claim **26**, wherein the ferromagnetic coating has a thickness between 1 μm and 50 μm.

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